DISSERTATION

LONG TERM EMISSION FROM PRE TREATED WASTE: COLUMN STUDIES

Submitted in fulfillment of the requirements for the degree of Master of Science in Engineering in the Civil Engineering Programme, University of Kwa Zulu Natal, Durban, South Africa.

RAFFAELLO MARCHETTI

December 2006

ABSTRACT

Emissions resulting from waste degradation processes have a high polluting potential and are responsible for negative impacts on the environment.

The potential environmental impact of a landfill is very closely related to the type of waste being disposed, the age of the landfill, prevailing climatic conditions and operational strategies.

In South Africa, untreated Municipal Solid Waste (MSW) is primarily disposed of in landfills that are governed by the "Minimum Requirements for Waste Disposal by Landfill" (DWAF, 1998). This document outlines the need for landfills to be constructed such as to follow environmentally acceptable methodologies for waste disposal. Research is now looking at solutions to treat MSW before landfilling and also reducing the long term effects associated with landfill disposal. Although Mechanical Biological Pretreatment (MBP) has been compulsory in Europe since 1995 and the technology is now mature, there are still uncertainties on the persistence of certain compounds such as ammonia, after final disposal.

This research aims to explore the efficiency of a pilot-scale MBP project conducted at the Bisasar Road landfill site in Durban with the specific objective of assessing long term emission potentials of the pretreated waste by simulation in leaching columns. The leaching process in the columns will be assessed in relation to waste composition, grain size distribution and degree of pretreatment.

TABLE OF CONTENTS

Chapter 1 : INTRODUCTION 1
Chapter 2 : LANDFILL WASTE DISPOSAL 4
2.1 INTRODUCTION 4
2.2 WASTE DISPOSAL IN SOUTH AFRICA 5
2.3 AN INTRODUCTION TO THE LANDFILL 5
2.4 WASTE BIODEGRADATION PROCESSES IN LANDFILL 7
2.5 LANDFILL EMISSIONS 11
2.5.1 Landfill gas 11
2.5.2 Leachate 16
Chapter 3 : MECHANICAL BIOLOGICAL PRETREATMENT OF WASTE 20
3.1 INTRODUCTION 20
3.2 BIOLOGICAL PRETREATMENT 20
3.3 MECHANICAL BIOLOGICAL PRETREATMENT (MBP) OF MUNICIPAL SOLID WASTE (MSW) 21
3.3.1 Mechanical Pretreatment 24
3.4 DOME AERATION TECHNOLOGY (DAT) 31
Chapter 4 : MATHERIALS AND METHOD 37
4.7.1 Temperature 46
4.7.2 pH 46
4.7.3 Conductivity 47
4.7.4 Chemical Oxygen Demand (COD) 47
4.7.5 Ammoniacal-Nitrogen (NH_3-N or NH_4-N) 48
4.7.6 Total Solids (TS) / Volatile Solids (VS) 50
Chapter 5 : RESULTS AND DISCUSSIONS 56
5.2 WASTE COMPOSITIONS 56
5.3 CHARACTERIZATION OF WASTE 59
5.3.1 Analysis on the eluates 59
5.4 COLUMNS MONITORING 59
5.4.1 Biogas testing 59
5.5 LEACHATE ANALYSIS 63
5.5.1 pH 63
5.5.2 Conductivity 66

5.5.3 Solids 69
5.5.4 Chemical Oxygen Demand (COD) 72
5.5.5 Nitrogen Compounds 78
5.8 SUMMARY OF RESULTS 85
Chapter 6 : CONCLUSIONS AND RECCOMENDATIONS 87
REFERENCES 90
APPENDIX 96

LIST OF FIGURES

Figure 2.1 Major stages of waste degradation (Christensen and Kjeldsen, 1995) 7
Figure 2.2 Changes in composition of landfill gas (Farquar and Rovers, 1973) 11
Figure 2.3 Changes in composition of leachate (Farquar and Rovers, 1973) 16
Figure 2.4 Water budget model showing only the significant components (Ham, 1988) 19
Figure 3.1 Trommel 25
Figure 3.2 Hammer mill 25
Figure 3.3 Rotating drum 25
Figure 3.4 Open windrow 26
Figure 3.5 Aerated static pile 26
Figure 3.6 Rotating Drum 27
Figure 3.7 Degradation stages during aerobic pre treatment 28
Figure 3.8 Natural Air Circulation in a Compost Windrow 33
Figure 3.9 The cross-section and plan of a typical windrow (Mollekopf et al, 2002) ... 34
Figure 3.10 Thermal flow of the Dome Aeration Windrow (Griffith, 2005) 35
Figure 4.1 Leaching column 38
Figure 4.2 Rubber rings 39
Figure 4.3 Upper and lower flanges 39

Figure 4.4 Biogas system 40
Figure 4.5 General scheme of liquid displacement method 41
Figure 4.6 Waste sieving at the Bisasar road landfill site 42
Figure 4.7 Leaching columns 43
Figure 4.8 Gas analyser 44
Figure 4.9 Sample on a stirrer 45
Figure 4.10 Filtration to obtain an eluate 46
Figure 4.11 pH and conductivity meter 47
Figure 4.12 Ammonia distiller apparatus 49
Figure 4.13 Sample for the ammoniacal nitrogen and nitrates analysis 49
Figure 4.14 Drying oven 51
Figure 4.15 Furnace 51
Figure 5.1 Components percentages of fresh waste sample 57
Figure 5.2 Components percentages of 16/8 weeks pre treated waste global sample 57
Figure 5.3 Components percentages of 16/8 weeks pre treated waste fine sample 58
Figure 5.4 Components percentages of 16/8 weeks pre treated waste coarse sample 58
Figure 5.5 Evolution of gas composition in Column 1 60
Figure 5.6 Evolution of gas composition in Column 2 60
Figure 5.7 Evolution of gas composition in Column 3 61
Figure 5.8 Evolution of gas composition in Column 4 61
Figure 5.9 Evolution of gas composition in Column 5 62
Figure 5.10 Fresh waste pH 63
Figure 5.11 16 weeks fine pH 64
Figure 5.12 16 weeks coarse pH 64
Figure 5.13 8 weeks fine pH 65
Figure 5.14 8 weeks coarse pH 65
Figure 5.15 Conductivity for fresh waste 66
Figure 5.16 Conductivity for 16 weeks pre treated waste fine 67
Figure 5.17 Conductivity for 16 weeks pre treated waste coarse 67
Figure 5.18 Conductivity for 8 weeks pre treated waste fine 68
Figure 5.19 Conductivity for 8 weeks pre treated waste coarse 68
Figure 5.20 TS and VS for fresh waste 69
Figure 5.21 TS and VS for 16 weeks pre treated waste fine 69

Figure 5.22 TS and VS for 16 weeks pre treated waste coarse 70
Figure 5.23 TS and VS for 8 weeks pre treated waste fine 70
Figure 5.24 TS and VS for 8 weeks pre treated waste coarse 71
Figure 5.25 COD concentration for fresh waste 72
Figure 5.26 COD concentration for 16 weeks pre treated waste fine 72
Figure 5.27 COD concentration for 16 weeks pre treated waste coarse 73
Figure 5.28 COD concentration for 8 weeks pre treated waste fine 73
Figure 5.29 COD concentration for 8 weeks pre treated waste coarse 74
Figure 5.30 COD removed from fresh waste 75
Figure 5.31 COD removed from 16 weeks pre treated waste fine 75
Figure 5.32 COD removed from 8 weeks pre treated waste fine 76
Figure 5.33 COD cumulative release from fresh waste 77
Figure 5.34 COD cumulative release from 16 weeks pre treated waste fine 77
Figure 5.35 COD cumulative release from 8 weeks pre treated waste fine 78
Figure 5.36 Ammoniacal - N concentrations from fresh waste 78
Figure 5.37 Ammoniacal - N concentrations from 16 weeks pre treated waste fine ... 79
Figure 5.38 Ammoniacal - N concentrations from 16 weeks pre treated waste coarse 79
Figure 5.39 Ammoniacal - N concentrations from 8 weeks pre treated waste fine 80
Figure 5.40 Ammoniacal - N concentrations from 8 weeks pre treated waste coarse 80
Figure 5.41 N concentations removed from fresh waste 81
Figure 5.42 N concentrations removed from 16 weeks pre treated waste fine 82
Figure 5.43 N concentrations removed from 8 weeks pre treated waste fine 82
Figure 5.44 N cumulative release from fresh waste 83
Figure 5.45 N cumulative release from 16 weeks pre treated waste fine 83

Figure 5.46 N cumulative release from 8 weeks pre treated waste fine 84
Figure 5.47 Nitrates cumulative release from fresh waste..... 84
Figure 5.48 Nitrates cumulative release from 16 weeks pre treated waste fine..... 85
Figure 5.49 Nitrates cumulative release from 8 weeks pre treated waste fine..... 85

LIST OF TABLES

Table 2.1 Volume of landfill gasses at methanogenic phase..... 12
Table 2.2 Typical landfill leachate composition (adapted from Robinson et al, 1989). 17
Table 3.1 Materials removed by sorting..... 24
Table 3.2 The effect of temperature range on aerobic degradation (Stentiford, 1996)30
Table 3.3 Sanitization requirements for composting in Europe (Stentiford, 1996)..... 31
Table 4.1 Starting conditions for each column 44
Table 4.2 Total Solids and Volatile Solids..... 52
Table 4.3 COD 53
Table 4.4 NH_3 and NO_x..... 54
Table 5.1 Waste composition of input material 56
Table 5.2 Results of eluate tests on the input material..... 59
Table 5.3 Summary of Columns results..... 86
Table 8.1 weekly extractions, ph, conductivity and gas analysis..... 96
Table 8.2 total solids and volatile solids..... 101
Table 8.3 COD 106
Table 8.4 N-ammonical and nitrates..... 111

PREFACE

The work presented in this dissertation was carried out under the supervision of Dr. Cristina Trois of the School of Civil Engineering, Surveying and Construction, University of Kwa-Zulu Natal, Durban, South Africa. This dissertation has been compiled in accordance with *The Style Guide for Dissertations,* prepared by the Faculty of Engineering of the University of Kwa-Zulu Natal, Durban and represents work written by Raffaello Marchetti, unless otherwise stated in the text.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. Cristina Trois, for her constant and precious support during the entire period of this master; moreover I would like to thank my parents which gave me the possibility to reach this important goal.

Chapter 1: INTRODUCTION

In the last century, modern society has faced the difficulty to manage the growing amount of waste generated, both in term of human health and to preserve the environment. The concentration of human population in urban areas has resulted in the creation of large quantities of waste, in addition to waste generated by the other forms of life. The first, and the most common solution, has been to collect and disposal of waste in a "container" known as "landfill". The concern for human health and the growing attention towards the environment have strengthened the interest on environmental themes and waste disposal technologies. For example, it has led to an increasing development of the concept of landfilling, moving from uncontrolled and unmanaged sites, often very dangerous for the environment and the public health, to sanitary landfills that are engineered with a predetermined design, managed and operated to high standards to ensure a minimal impact on the neighboring environment. On the other way, there is always the necessity to implement the landfilling techniques to offer a completely safe disposal at the lowest possible cost. So, the key word is "waste management"; how can find the best way to manage the growing amount of waste that each day the mankind produces? There are many options to create a sustainable landfill but each one must ensure the lowest impact for the human health and for the environment avoiding any contamination in terms of pollution of soil and water. A definition of waste is given below:

"An undesiderable or superfluous by product, emission, or residue of any process or activity which has been discarded, accumulated or been stored for the purpose of discarding or processing. It may be gaseous, liquid or solid or any combination thereof, and may originate from a residential commercial or industrial area. This definition includes industrial waste water, sewage, radioactive substances, mining, metallurgical and power generation waste" (Visser, 2002).

Waste can be divided in two large categories: General Waste and Hazardous Waste.

General Waste includes a wide range of heterogeneous materials such as food waste, garden wastes, paper, textiles plastics, metals, rubber, dirt, construction waste, glass, wood waste, etc.

After being collected, the waste can take several ways in connection with different technical, environmental or economical reasons, and it goes through different stages to recover the recyclable fractions, minimize the volume and stabilize its component:

1. waste reuse: some objects are removed and processed for reuse, for example tyres, bottles, etc.
2. waste recovery: by processing of selected RDF (Refuse Derivate Fuel) material is possible to obtain fuel; moreover energy is recovered by combustion of waste or combustion of methane that is produced throught the anaerobic degradation of waste.
3. waste treatment: to stabilize the waste by reducing the organic fraction. Available treatments include thermal incineration and mechanical biological pretreatment.
4. waste disposal: the remaining amount of waste is disposed directly in landfill.

Case studies on an international level have shown that through Mechanical Biological Pretreatment (MBP) of Municipal Solid Waste, landfill behaviour can be improved, so that the long term polluting potential is reduced significantly (Stegmann, 2005). This study reports on the applicability and efficiency of MBP in South Africa. Waste treatment in passively aerated open windrows, using the Dome Aeration Technology (DAT), was identified as an appropriate technology due to low construction and operational resource requirements (Trois et al, 2005). Three self-aerated windrows were set up at the Bisasar Road Landfill in Durban in order to study the efficiency of the process for different composting timeframes (8 and 16 weeks). The pretreated material resulting from the landfill was analysed in leaching columns. The effect of different degrees of degradation was studied in relation to waste composition and rate of irrigation.

The overall objectives of the research were to:

1. Assess the efficiency of passively aerated open MBP windrows
2. Study degradation processes of pretreated waste
3. Investigate the long term emissions from MBP waste
4. Study the effect of waste particle size, composition and degree of pretreatment on the formation of leachate.

The methodological approach to achieve the above stated objectives was as follows:

- study the degradation process in anaerobic environment of pre-treated waste (8 weeks-16 weeks) using columns,
- study of the effect of grain size on leachate contamination and biogas production during leaching tests of pre treated waste.

Five PVC leaching columns were set up at the Environmental Engineering Laboratory at the University of Kwa-Zulu Natal. The columns were fed with distilled water to allow for a fixed 7-day water-waste contact time. The kinetics of the leaching process will be determined by estimating the percentage of removal of organics and nutrients in the leachate and the evolution of biogas production during the experimental time.

The columns, named as C1, C2, C3, C4, C5, are filled respectively with:
Column C1 filled with fresh waste
Column C2 filled with 16 weeks pre-treated waste $\varphi < 50$ mm (fine)
Column C3 filled with 16 weeks pre-treated waste $\varphi > 50$ mm (coarse)
Column C4 filled with 8 weeks pre-treated waste $\varphi < 50$ mm (fine)
Column C5 filled with 8 weeks pre-treated waste $\varphi > 50$ mm (coarse)

Set up and weekly operation of the columns are reported and described in more depth in Chapter 4 (Matherials and Method).
It is envisaged that the results of this research will be of interest for waste regulators, waste managers and scientists. The findings will clarify the dynamics of biodegradation and contaminant removal from pre-stabilized waste. Comments on the efficiency of short-term and prolonged pretreatment will be provided together with recommendations on the appropriateness of waste separation, prior to pretreatment.

Chapter 2: LANDFILL WASTE DISPOSAL

2.1 INTRODUCTION

The improvement of living standards and the growing population, both in South Africa and worldwide, has facilitated the generation of large volumes of waste.

The use of a landfill as a waste disposal method is the most common, and in several countries, the only available system to dispose waste.

This is the final option for the fresh waste or for the residues of waste treatment.

The disposal of municipal solid waste (MSW) in controlled or sanitary landfills is the most common means of disposal worldwide and in South Africa.

A sanitary landfill can be defined as "a scientific method of disposing of solid waste on land" with the dual purpose of eliminating public and environmental hazards and minimizing nuisances without contamination of surface or groundwater resources (Lombard, 2005).

Modern landfills have several systems to reduce the risk of contamination to the environment both by gaseous and liquid emissions.

The waste directly disposed in landfill contains a large quantity of organic substance; after the coverage of fresh waste with soil, the layer of compacted waste is isolated from the atmosphere and anaerobic conditions are established where populations of microorganisms degrade the waste into CO_2, CH_4, and soluble simple by products.

Waste comprises of a heterogeneous mass of material which varies according to the source and with time. Following its deposition in a landfill site and often before, the organic fraction of the waste will begin to undergo degradation through chemical and microbiological action, resulting in the production of biochemical breakdown products and the liberation of gases. The infiltration of rainfall, ground and surface waters into the waste mass, coupled with this biochemical and physical breakdown, produces a leachate which contains soluble components of the waste, suspended solids and micro-organisms.

The main emissions from landfills are:

1. Landfill gas: is generated by bacteria during the anaerobic degradation of waste; the composition depend on the stage of biodegradation, the moisture content of the waste and the nature of the waste itself.
2. Landfill leachate: is the liquid that has gone throught the different waste layers and contains very highly polluted dissolved or suspended materials.
   The nature of the leachate depends on the type and the composition of the waste, the stage of waste biodegradation, the moisture content in the waste body and the operational procedures in landfill.

2.2 WASTE DISPOSAL IN SOUTH AFRICA

Waste disposal in South Africa is governed by the "Minimum Requirements for Waste Disposal by Landfill" (DWAF, 1998). This document outlines the need for landfills to be constructed so to follow environmentally acceptable methodologies for waste disposal.
In South Africa landfills are classified according to the type of waste, size and their potential for leachate generation (Novella et al., 1999).
The waste type is divided into general and hazardous waste with general waste being municipal solid waste (MSW) and hazardous waste that may pose environmental and health risks.
Hazardous waste landfills are classified by the amount and nature of the hazardous waste received and subdivided in h:H landfills (hazardous landfills) and H:H landfills (very hazardous landfills).

2.3 AN INTRODUCTION TO THE LANDFILL

Sanitary landfilling may be described as "a controlled, engineered burial of wastes" (Baum and Parker, 1973).
A sanitary landfill is the most economical method of waste disposal where land is available and provides the final step in the waste management process. Modern landfills are designed to avoid any contamination of the environment; therefore understanding the waste degradation processes plays a very important role in determining and

reducing the potential adverse impacts that landfills may have during and after operational life.

After the waste deposition in a landfill site, the organic fraction of the waste undergoes degradation through chemical and microbiological action; producing landfill gas and leachate (Lombard, 2000).

This degradation develops through physical, chemical and biological processes.

Landfills may be considered as bioreactors with refuse and water as inputs and liquid (leachate) and gas (landfill gas) as products (Bowers, 2002).

- Physical decomposition is considered as the leaching of the material from the waste in accordance with the changes in physical characteristics as a result of waste degradation.
- Chemical decomposition includes the dissolution of materials from the waste.
- Biological decomposition has an important role in the degradation of the wastes in landfills.

2.4 WASTE BIODEGRADATION PROCESSES IN LANDFILL

According to Christensen and Kjeldsen (1995), waste degradation of the organic fraction of waste materials within a landfill may be described through a five stage process, as illustrated in figure 2.1 below.

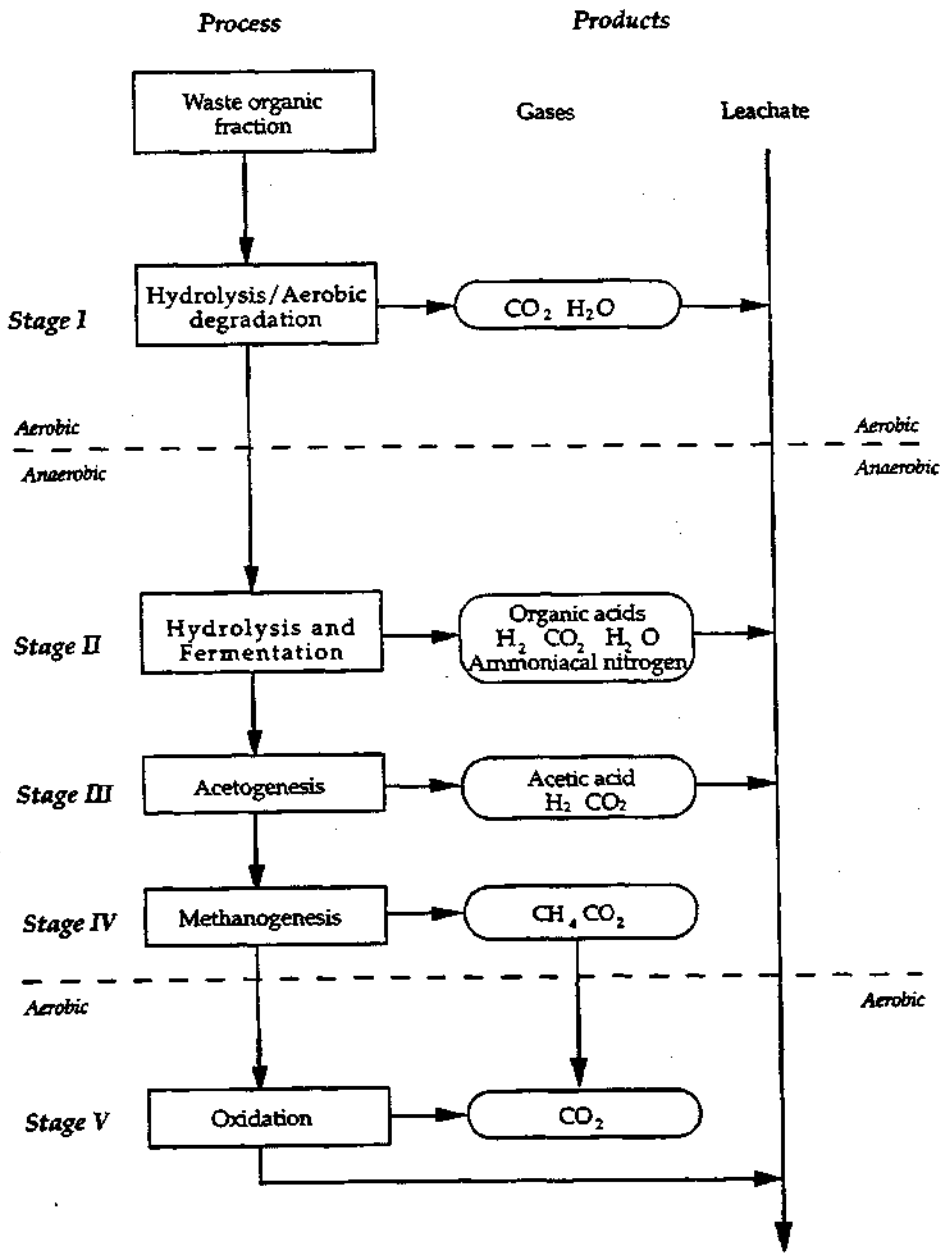

Figure 2.1 Major stages of waste degradation (Christensen and Kjeldsen, 1995)

The first and fifth stages occur under aerobic conditions (in the presence of oxygen), while the others stages occur under anaerobic conditions (in the absence of oxygen).
As oxygen levels decrease the aerobic micro-organisms are gradually replaced by facultative anaerobes; bacteria which can tolerate low oxygen levels.

Stage I: Hydrolisis/Aerobic Degradation (Christensen & Kjeldsen, 1989)
Immediately after waste deposition at the top side of the landfill this first process occurs.
The waste is exposed to atmospheric oxygen and the characteristic fresh waste smell is felt.
During this first phase the organic fraction is metabolized by aerobic micro-organisms (oxygen consumers) present in the waste.
These microorganisms convert degradable carbohydrates to simple sugars such as glucose, carbon dioxide, water and other low molecular weight organic compounds.
This stage is relatively short and ends after a few days after waste landfilling.
If during this phase of decomposition leachate is obtained, it will have a very acidic pH and a high chemical oxygen demand (COD) as a result of an organic material degradation.
However, due to the fact that the leachate is usually not largely produced in this early stage of decomposition because the refuse has not reached field capacity, it is more appropriate at this stage to speak only about moisture accumulation.
The term field capacity refers to the amount of liquid a given mass of material will absorb, prior to percolation of waste due to gravitational forces (Bowers, 2002).
Moreover, the aerobic decomposition includes production of heat due to exothermic reactions which can cause the temperature in the refuse to rise to 70 - 90 °C.
When the oxygen starts to be depleted and the aerobic micro-organisms are superseded by facultative anaerobes, an anaerobic condition is develops.
As stated in Robinson (1989), when the covering layers are sufficiently thick to exclude the waste from the atmosphere and the oxygen remaining in the waste is consumed by the highly active aerobic microbes leading to anaerobic conditions, this is the onset of the acid stage.

Stage II: Hydrolisis and Fermentation (Acidogenesis)

This phase is a fermentation stage where groups of microorganisms which can tolerate low levels of oxygen (facultative anaerobes) start to develop and anaerobic conditions occur.

Carbohydrates, lipids and proteins are hydrolyzed and then fermented by bacteria into volatile acids, carbon dioxide, mineral compounds and soluble acids.

The leachates produced have high COD and BOD values, the pH values are typically around 5-6, and high ammonical-nitrogen concentrations are present.

The aggressive chemical nature of the leachate also results in high levels of iron, manganese, zinc, calcium and magnesium.

The gas produced during this phase is primarily carbon/dioxide with lesser proportions of methane (CH4); H2 and H2S may also be produced during this stage (Robinson, 1989).

The duration of the acid phase is generally between a few months to two years; in the specific case of warm climates such as in subtropical areas of South Africa and Australia, the duration of this stage was found to be between six and nine months (Bowers, 2002).

The gradual establishment of the sensitive methanogenic bacteria results in the formation of a dynamic equilibrium between the acid phase bacteria and methanogenic bacteria; this signifies the end of the acid stage and the beginning of the methanogenic stage.

Stage III: Acetogenesis

Anaerobic conditions allow a further development of anaerobic bacteria and a continuation of the fermentation process.

In this phase the soluble acids formed by the activities of the fermentative bacteria of the previous stage are converted to acetate, carbon dioxide and hydrogen; moreover other bacteria convert carbohydrates, hydrogen and carbon dioxide into acetic acid.

The leachate produced in this phase will characteristically have a low pH, a high COD reflecting large amounts of partially degraded organic material, and a high dissolved inorganic content. A large amount of heavy metals are mobilized due the decreasing pH.

During this stage, the gases generated from the waste mass in a balanced system are predominately carbon dioxide, hydrogen and methane, however, CO2 production rate declines and H2 production ceases. This third phase can last from years to decades.

Stage IV: Methanogenesis

This stage is dominated by organisms which cannot tolerate the presence of oxygen; in fact this is a completely anaerobic phase and is characterized by a production of methane gas. The soluble organic compounds formed during the acid phases are metabolized by methane-generating bacteria (methanogens) and converted to methane and carbon dioxide. As a result of the removal of these compounds, the leachates produced during the methanogenic stage are significantly less aggressive, with low COD values, low BOD to COD ratio and a more neutral pH; however ammonical nitrogen concentrations are still high. The gas production rate, an indication of biological activity, reaches a peak after many years and gradually decreases until the waste is fully stabilized, and there is no longer material available for the sustenance of the bacteria. The decomposition of most degradable wastes is referred especially to this phase due to the large production of methane and carbon dioxide which remains over the life of the landfill, and lasts longer than other phases (up to several decades).

Stage V: Oxidation

In this final stage the decomposable components of waste are exhausted, aerobic conditions are progressively re-established and facultative aerobic and anaerobic microorganisms such as methane oxidizing organisms are reintroduced. This process can lead to the release of substances as heavy metals which were stable during the preceding anaerobic stage. Continued degradation of the waste produces humic-like substances. For illustrative purpose, Cooper (1992) gives the following stechiometric equations for the above processes (using glucose as the waste):

I: Aerobic decomposition of glucose (no gas produced)

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

II: Hydrolysis: No gas production

III: Anaerobic acid fermentation of glucose (CO_2 and H_2 gas produced):

$$C_6H_{12}O_6 \longrightarrow CH_3COOH + C_2H_5COOH + CO_2 + H_2$$

$$C_6H_{12}O_6 \longrightarrow C_3H_3COOH + 2CO_2 + 2H_2$$

IV: Methane fermentation of glucose (CO_2 and CH_4 gas produced):

$$C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4$$

2.5 LANDFILL EMISSIONS

Landfill gas and leachate are the most important long term emissions emanating from a landfill due to stabilization processes occurring within the waste body.

2.5.1 Landfill gas

Landfill gas is a mixture of gases produced by bacterial activity within the waste body during the different phases of degradation.

Figure 2.2 shows the changes in gas composition as the age of the landfill progresses.

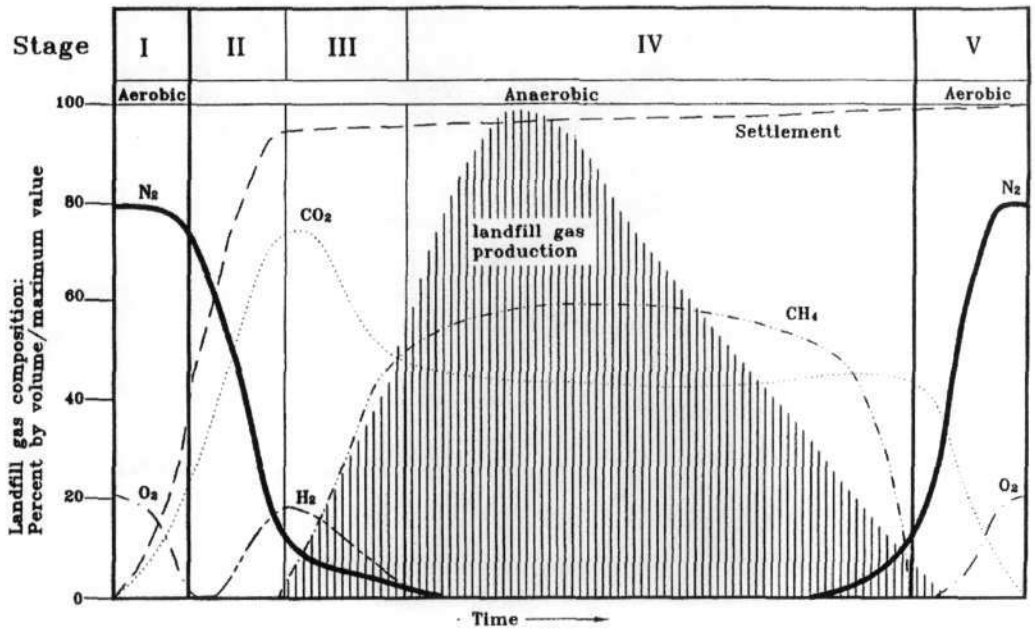

Figure 2.2 Changes in composition of landfill gas (Farquar and Rovers, 1973)

During the aerobic phase of degradation, oxygen levels become depleted with concomitant rise in levels of carbon dioxide. Hydrolysis and fermentation causes the levels of nitrogen to fall and the levels of carbon dioxide and hydrogen to rise.

The transition to anaerobic conditions occurs quite quickly as the soil layer used to cover the waste at the end of each day restricts the amount of oxygen entering the wastes from the atmosphere. The compaction of both the waste and the soil layer that occurs during the land filling process also helps restrict diffusion of oxygen into the covered waters (Lamborn, 1999). As acetogenesis begins the concentration of methane gradually rises; after the initial relatively short phases (1 – 3), an often very long methanogenic phase begins where typical contents of CH4 and CO2 are 55% by volume and 44% respectively (Christensen and Kjeldsen, 1995). For the methanogenic phase, the highest gas production rates are expected in the beginning of the phase, while the production rate is expected to be very small in the oxidation phase (Christensen and Kjeldsen, 1995).

Landfill gas may include hydrogen sulphide, which is generated by a group of sulphate reducing bacteria which act on sulphate within the waste (Lombard, 2005). The landfill gas also contains trace amounts of volatile fatty acids (VFA) that are responsible for the typical sour odor associated with "biogas". The typical major components of landfill gas (LFG) at methanogenic phase are shown in Table 2.1 below.

Table 2.1 Volume of landfill gasses at methanogenic phase

Component	**Volume (%dry weight basis, excluding moisture content)**
Methane (CH_4)	45% to 58%
Carbon Dioxide (CO_2)	32% to 45%
Non-methane Organic compounds	0% to 0.25%
Hydrogen Sulfide (H_2S) and other sulfur compounds[7]	varies (10-200 ppm)
Volatile Organic Compounds (VOC)[8]	0% to 0.1%
Carbon Monoxide (CO)	0% to 0.2%
Moisture	up to 14% (increasing with gas temperature)
Hydrogen(H_2)	trace to > 1%
Nitrogen (N_2)	0% to 3%

Source: Adapted from Tennessee Division of Solid Waste Management: Landfill Gas Monitoring and Mitigation. 1999.

Therefore, the main components of landfill gasses are:

- Methane (CH_4)

  Methane (CH_4) is colourless, odorless, asphyxiant, flammable non-toxic gas that is lighter than air with a vapor density of 0.6; is also explosive between the concentrations of 5% - 15% by volume in air.

- Carbon Dioxide (CO_2)

  Carbon dioxide (CO_2) is a colourless, odorless, non-flammable, toxic gas that is heavier than air with a vapor density of 1.53. At a level of 3% v/v in air breathing becomes labored with resultant headaches. At a level of 5-6% v/v those symptoms becomes severe and at 10% visual disturbances, tremors and loss of consciousness can occur. The accepted limit is 1.5% v/v in air and above this figure carbon dioxide is considered hazardous (Lombard, 2000). Atmospheric CO_2 is a limiting factor in photosynthesis and is essential to plants. However, when present at high concentrations in soils, it can result in asphyxia due to oxygen displacement or even be directly toxic to plants. The normal CO_2 in soils varies between 0.04 and 2%. Landfill cover soils, is directly toxic to plants roots, even if there is enough oxygen available. An indirect effect of carbon dioxide could be a lowering of the soil pH and the consequent changes in soil composition. Normal development can occur till 5% (Maurice, 1998).

There are many parameters which can influence the production rate and the composition of landfill gas such as:

- Temperature

  The microorganisms responsible for the biodegradation of MSW in a landfill carry out this activity effectively at a certain temperature and generally the rates of degradation of the waste increase with temperature up to an optimum temperature specific or suitable for the microbe involved. The temperature of 40°C is considered as optimum with significant inhibition over 55C (Gurijala, 1993) while rise in temperature from 20 – 30 and 40°C can increase the methane production rate up to 100 times (Buivid, 1980 and Ehrig, 1984). Temperatures of 35°C - 40°C during anaerobic process may be reached within landfill even in

moderate climates (Christensen and Kjeldsen, 1989). Anaerobic heat generation only constitutes about 7% of the aerobic heat generation and is often neglected (Rees, 1980).

- Oxygen (O_2)

  The anaerobic bacteria and the sensitive methanogenic bacteria in particular, need absence of free oxygen to grow. Normally oxygen enters within landfill by diffusion from the atmosphere.

- pH and Alcalinity

  The optimal pH is between 6.7 and 7.2 and alkalinity should be greater than 2000 mg/l (based on an analogy to anaerobic digestion processes) (Farquhar, 1973). Hydrogen and acetic acid conversion by methanogenic bacteria, can lead to a build up of volatile organic acids and consequently a drop in pH, which may inhibit methane formation. This can eventually stop or reduce the methane generation.

- Water content

  A refuse moisture content of 50 to 100 percent of the dry weight of wastes (33 to 50 percent, wet weight basis) is required for active methane generation (Ham, 1979). The main effect of the increased water content, besides limiting oxygen transport from the atmosphere, is probably the facilitated exchange of substrate, nutrients, buffer, and dilution of inhibitors and spreading of micro-organisms between the waste micro environments (Christensen and Kjeldsen, 1989).

- Hydrogen

  The methanogenic processes are affected by the hydrogen partial pressures in the landfill. When the partial pressures are low, fermentative bacteria produce hydrogen, carbon dioxide and acetic acid; when the partial pressures are high, the bacteria produce hydrogen, carbon dioxide, as well as the organic acids ethanol, butyric acid and propionic acid. The organic acids may be further converted if the hydrogen partial pressure is low. In the event that the hydrogen pressure increases, organic acids will be generated but not further converted leading to a build-up of volatile organic acids, a decrease in the pH and possibly inhibition of the methane formation. (Christensen and Kjeldsen, 1989).

- Sulphate

  Inhibition of methanogenesis by sulphate has been observed in a variety of environments. Sulfate-reducing bacteria compete with methanogenic bacteria for

electron donors like acetate and H2; therefore, methanogenesis is hindered in sulfate-rich environments like construction and demolition debris landfill, which contain gypsum, when sulphate is present in high concentrations the formation of methane is significantly reduced (Stegmann and Spendlin, 1985).

- Nutrients

  The anaerobic ecosystem must have access to, in addition to organic matter, all the required nutrients and in particular nitrogen and phosphorous. All the necessary micronutrients e.g. sulphur, calcium, magnesium, potassium, iron, zinc, copper, cobalt and selenium are considered to be available in most landfills (Christensen et al, 1996). Nitrogen and phosphorous in anaerobic degradation are less critical than in aerobic system. In most landfills, the presence of nitrogen and phosphorous will not be limited, but insufficient homogenization of the waste may lead to areas in the fill that are nutrient limited.

- Inhibitors

  The methane-forming environment is generally considered to be sensitive to inhibitors. Macro-ions such as sodium, potassium, calcium magnesium and ammonium may have inhibitory effects on the formation of methane when present in high concentration of methane when present in high concentration (> 200mg/l). According to Johnson (1981) the inhibition by specific organic compounds rarely occurs because the levels required for inhibition are too high to be found in the landfill environment. The production and accumulation of landfill gas within the landfill raises the gas pressure in the landfill above atmospheric pressure. The resulting pressure gradient acts as a driving force causing the gas to diffuse out of the landfill, into the surrounding soil strata or in air. This diffusion occurs along the path of least resistance, i.e. through cracks, the landfill cover and laterally through the surrounding topsoil (Lamborn, 1999). *The generation of landfill gas poses a threat to the environment. There are four* main environmental problems that arise from the landfill gas generation as follows:

  - Safety concerns associated with the migration of a potentially explosive gas into the surrounding areas,
  - A detrimental effect on vegetation,
  - Odour generation,
  - Contribution of the gases to the greenhouse effect.

These problems could be reduced or avoided through the use of landfill gas prediction tools and a good understanding of all the factors affecting landfill gas generation within landfills.

2.5.2 Leachate (Farquar & Rovers, 1973)

Leachate can be defined as an aqueous solution with a high polluting potential arising when water is permitted to percolate through decomposing waste; it contains the final and intermediate products of decomposition, various solutes and waste residues (Bowers, 2002). Each phase of waste degradation has its characteristic leachate composition; leachates generated during the early stages of anaerobic degradation are characterized by high concentrations of volatile fatty acids, acidic pH, high BOD to COD ratio and high levels of ammoniacal nitrogen and organic nitrogen. The low redox potential of this leachate facilitates the production of soluble reduced state metals including chromium, iron and manganese The pH then rises causing the metals to precipitate sulphides, hydroxides and carbonates. Following the onset of methanogenesis phase, many of the fatty acids responsible for the acidic pH and high BOD have been converted to methane and carbon dioxide; methanogenic leachates are characterized by low concentrations of fatty acids, neutral to alkaline pH, lower levels of ammoniacal nitrogen and low BOD to COD ratio. The changes in composition of leachate as the phases of decomposition progress are showed in Figure 2.3

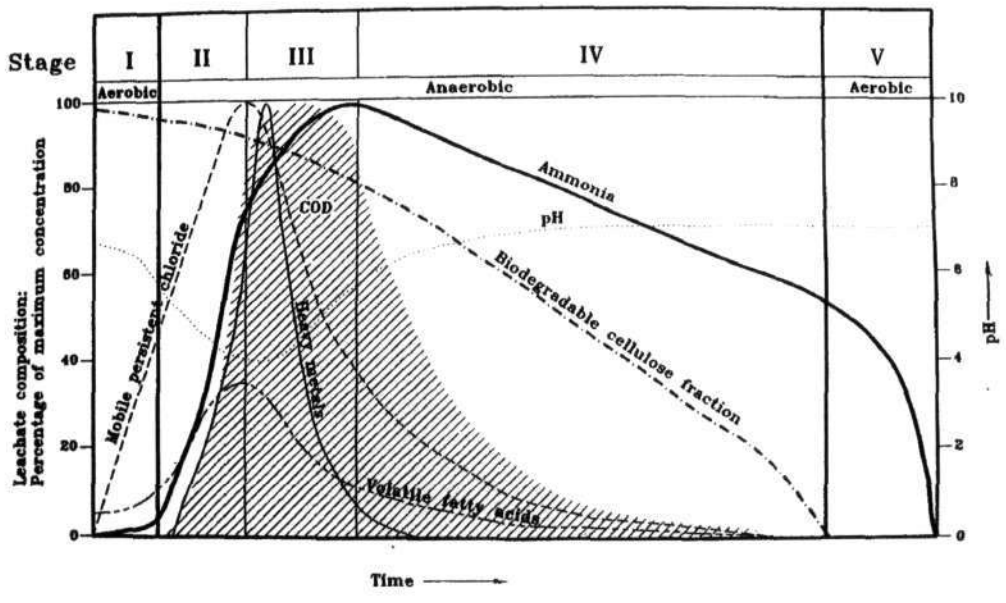

Figure 2.3 Changes in composition of leachate (Farquar and Rovers, 1973)

The typical composition of leachate from municipal solid waste (MSW) landfills is below summarizes in Table 2.2 and expressed in mg/l except for pH:

Table 2.2 Typical landfill leachate composition (adapted from Robinson et al, 1989)

Determinand	Range
pH	6.2 – 7.4
COD	66 - 11600
BOD	< 2 - 8000
TOC	21 - 4400
Ammonical - N	5 - 730
Nitrate - N	< 0.5 – 4.9

The potential for leachate generation is defined by equation 2.1 (Novella et al., 1999):

$$B = R - E$$

Where:

B = Climatic water balance in mm of water

R = Rainfall in mm of water

E = Evaporation from the soil surface in mm of water

If B is positive the landfill has the potential of generating leachate and proper leachate management systems must be implemented. Rainfall most likely will percolate through the landfill body; the water is absorbed by the waste until field capacity is reached. Field capacity is defined as the volume of liquid which can be absorbed by a given weight of solid waste until the release of excess water under gravitational forces (Novella et al., 1999). The field capacity of waste varies according to its type, pre-treatment and degree of compaction (Lombard, 2005). Models have been derived to predict the quantity of leachate provided; the most common model is the water balance model useful to assess a proper leachate management plan. According to Knox (2000), water balance calculations are used to:

- Predict leachate volumes at new landfills; this is necessary in order to design and budget correctly for leachate management facilities. It is also necessary for the evaluation and planning of cell sizes during operation of the landfill.
- Interpret and evaluate leachate levels and leachate flow rates at existing landfills.

The water balance calculation for a landfill compares the quantities of all liquids entering and leaving the site during a specified period (Knox, 2000). The standard water budget equation for any hydrologic system is (Knox, 2000):

$$\text{rate of inflow} - \text{rate of outflow} = ds/dt$$

where:

ds/dt = rate of change in the quantity of liquid

S = liquid stored within the system

The above equation is usually re-arranged and combined with assumptions about storage characteristic for the calculation of the change in free leachate volume during a specified time period, typically one year; thus (Knox, 2000):

$$L = \text{water inputs} - \text{leachate outputs} - aW$$

where:

L = free leachate retained at the site

a = absorptive capacity of the waste (m3/tonne)

W = waste input during the period (tonne)

While the equations showed above may appear very simple, estimation of its components is not. Liquid inputs and outputs may be numerous, depending on circumstances, and may include (Knox, 2000):

Inputs: precipitation, surface run-on, groundwater discharge, liquid un waste, leachate recycle, irrigation water.

Outputs: evaporation, transpiration, surface run-off, surface seepage, groundwater recharge, leachate abstraction, landfill gas removal, waste fermentation.

Inputs and outputs with the most significant contribution to leachate production are shown in Figure 2.4.

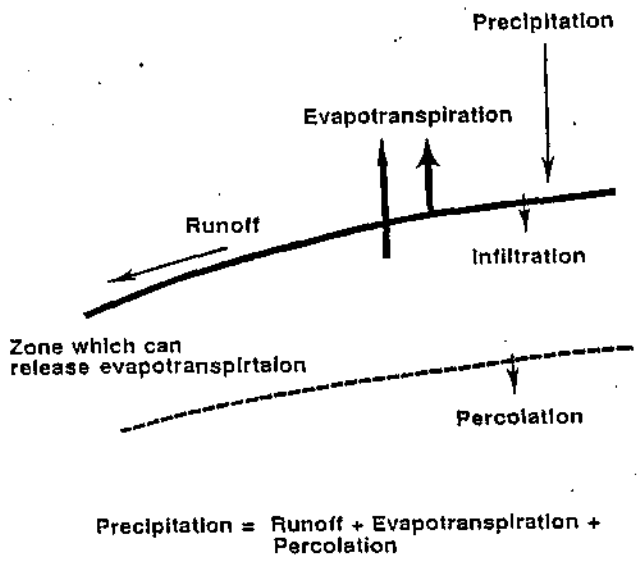

Figure 2.1 Water budget model showing only the significant components (Ham, 1988)

Another very important component of the water budget that is not shown in this model is the soil moisture storage. It is the moisture retained after a given amount of accumulated potential water loss or gain has occurred. Accumulated potential water loss or gain is the infiltration minus evapotranspiration; it is negative for loss and positive for gain. The water balance model offers an helpful tool for landfill operators to assess their leachate management plan and control practical operation.

Chapter 3 : MECHANICAL BIOLOGICAL PRETREATMENT OF WASTE

3.1 INTRODUCTION

In recent years, focus has shifted from landfilling techniques to reducing the harmful effects of waste decomposing. Waste management techniques and alternatives to land filling are well established in developed countries while in South Africa emphasis has been placed to investigate others economically viable solutions. Waste pretreatment processes are aimed at reducing the polluting potential and stabilizing the readily and moderately decomposable organic compounds prior disposal. Not all existing Mechanical Biological Treatment (MBP) systems are applicable to South Africa due to technological and financial constraints, climatic conditions and lack of appropriate technologies. An estimated 85% of MSW generated in South Africa is landfilled, with the remaining 15% unaccounted for as a result of being generated by rural communities (Fourie and Morris, 2002). In accordance with South Africa's growing need for waste disposal alternatives, the Dome Aeration Technology (DAT) system is currently being evaluated as appropriate to facilitate the use of labour which is available and the low costs especially if compared to other technologies. The two main types of available pretreatment technologies are thermal pretreatment (incineration) and mechanical biological pretreatment (Stegmann, 2005). The biological pretreatment, generally a mechanical biological pretreatment, can be applied as a single treatment operation or in combination with thermal pretreatment (Soyez, et.al1997). To summarize, the categories for treatment processes include:

- Biological: Aerobic and anaerobic treatment systems
- Thermal: Incineration
- Hybrid: Mechanical and Biological combinations

3.2 BIOLOGICAL PRETREATMENT

Aerobic Processes

Aerobic decomposition is the breaking down of organic substances by microorganisms in presence of oxygen; aerobic pretreatment can achieve waste stabilization, fuel production or composting products. The different techniques used in aerobic decomposition are:

- Composting in open windrows
- Aerated static piles
- Drum systems

Anaerobic Processes

The anaerobic treatment process depends of microbial activity which breakdown organic compounds in absence of oxygen; anaerobic technology generates products such as biogas, which can be a suitable source for energy generation.

3.3 MECHANICAL BIOLOGICAL PRETREATMENT (MBP) OF MUNICIPAL SOLID WASTE (MSW)

By mechanical-biological pretreatment (MBP) of residual municipal solid waste the behaviour of landfills can be significantly improved. After MBP the organic content (COD and BOD_5), total organic carbon, and total nitrogen in the leachate, as well as the gas production rate, are reduced to values lower than 90% of these present in the fresh untreated waste. The volume of the stabilized material to be disposed on landfills decreases enormously, by up to 70% (Munnich et al, 2005). MBP has a waste volume reduction effect and better compactability of the waste due to the mass reduction and density of materials; this results in a valuable landfill airspace saving.

Conventional domestic waste landfill behaviour shows that 90% of degradation products are emitted as landfill gas and 10% emitted as leachate; with MBP gas emissions are reduced by 90% and an 80% reduction in the leachate organic load is seen (Scheelhaase and Bidlingmaier, 1997). Field studies indicate that the mechanical biological pretreatment of waste can significantly reduce the organic strength of leachate. Untreated waste in a landfill produces high organically loaded leachate from the acid phase; due to MBP this acid phase eliminated and the leachate produced resembles that of non-pretreated landfills in the methanogenic phase (Bone et. al.; 2003). A reduction in ammonical nitrogen concentrations is also reported (Scheelhaase et. al.; 1997; Ziegler, 1997; Bone et. al.; 2003); however, the levels of COD from MBP landfills are often as high as that of non-pretreated landfills with values ranging between 500 and 4000mg/l and this is in spite of BOD levels frequently below 100mg/l (Bone et.

al.; 2003; Kuehle-Weidemeier et. al.; 2003). The COD of MBP leachates is indicative of slowly or non-biodegradable compounds, reflected by low BOD values (Bone et.al; 2003). After MBP and due to low biological activity, gas formation occurs within a long period of time. The biogas produced from adequately pretreated waste is significantly lower than for untreated waste; previous investigations indicate a total reduction in gas volumes of the order of 90% (Scheelhaase et. al.; 1997). The volume of gas produced by pretreated waste is sufficiently small not to warrant the installation of an active gas extraction system with biological oxidation of methane in the landfill- capping layer being sufficient to remove the trace quantities that are produced later (Leikam et.al.; 1997).
MBP aims at reducing the biodegradability of the waste body and thus reducing the landfill pollution and improving the landfill behaviour. The following aspects can be achieved by MBP:

- Reduction of mass and volume of waste to be landfilled by reducing biodegradable elements
- Reduction of the landfill emission potential
- Homogenization and stabilization of waste
- Reducing human health risks

Others advantages and disadvantages can be considered and evaluated for specific situations:

Advantages

- Technology that can be applied to large volumes of residual waste
- Reduces costs of waste disposal and aftercare of landfills
- Significant landfill volume/area reduction, conserving land resources (Muntoni, 2005)
- Biodegradability of waste is reduced and stability of waste is increased by the MBP process, thereby reducing methane and leachate production on landfills (Muntoni, 2005)
- On-site odour and litter is reduced therefore increasing aesthetic value of landfills
- Potential hazardous waste contaminants in the waste stream such as batteries, solvents, paints fluorescent light bulbs etc. will not reach municipal landfill sites due to waste sorting stage prior to treatment (Muntoni, 2005)

- The RDF from pretreated waste yields a higher calorific value compared to untreated residual waste
- Recycling, reusing and recovering of waste materials will be maximized due to mechanical sorting (Visvanathan, 2004)

Disadvantages

- Pretreatment and disposal of waste is particular to a certain region
- Cost of waste management prior to landfilling is increased due to an additional treatment stage and an establishment of a sorting facility
- Assessment of the waste stream is required to establish if MBP is suitable; for example composts may not be suitable for use after pretreatment of the waste

Moreover emissions from biological pretreatment processes are possible:

- Carbon dioxide and methane produced by aerobic and anaerobic activities (Soyez and Plickert, 2002)
- Organic compounds generated by biological activities
- Volatile substances left from waste body
- Germs and bacteria produced during biological processes

However the degree of benefit is dependant on the following site specific factors (Bone at.al, 2003):

- The extent of source separation
- The waste input
- The type of mechanical pretreatment
- The type and duration of the biological pretreatment

The above factors influence the nature of the pretreated waste material which is eventually deposited into the landfill and ultimately influence the potential emission of the landfill.

Hybrid pretreatments include Mechanical Biological Pretreatment of Municipal Solid Waste (MSW) before the disposal into landfill sites; the biodegradable waste components are treated through combinations of mechanical and biological processes. (Leikam and Stegmann, 1997). The Mechanical Biological Pretreatment of solid waste (MBP) is a two stage process and involves the mechanical preparation and the biological degradation of the waste; both play an important role in reducing the amount of waste material to be landfilled.

3.3.1 Mechanical Pretreatment

Sorting

Re-usable components are separated from the waste body through:

- Manual Separation
- Ballistic separation (separation of material with high calorific value and high mineral content) (Heerenklage and Stegmann, 1995)
- Magnetic separation (use of magnetic conveyor belts to remove ferrous elements)

Typical elements that are removed by sorting are shown in Table 3.1 below:

Table 3.1 Materials removed by sorting

METHOD	MATERIALS REMOVED
Manual separation	Plastics, oversize elements.
Ballistic separation	Plastics, paper, glass, stone
Magnetic separation	Ferrous metals

Screening

This separation method is achieved mainly by rotating sieve drums; a rotating drum with a sieve or screen size of between sixty and a hundred millimeters is used. Fine materials such as soil and organic materials fall through the screen and larger fractions are retained in the screen. A typical screening technique using a trommel is showed in Figure 3.1

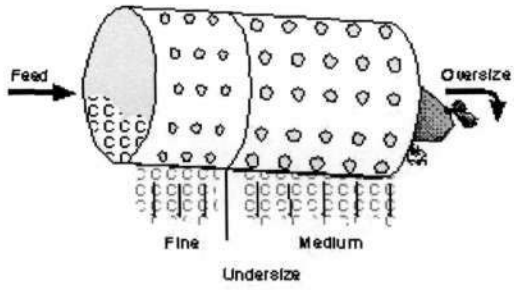

Figure 3.1 Trommel

Shredding

This method involves breaking down large portions of waste into smaller fractions; this is useful as a volume reduction hence an increase of surface area of the waste which allows for an enhanced biological activity and for a faster composting rate. Shredding devices include: hammer mills, shear shredders and rotating drums (Figure 3.2 and 3.3).

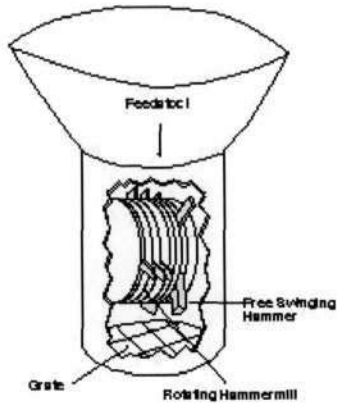

Figure 3.2 Hammer mill

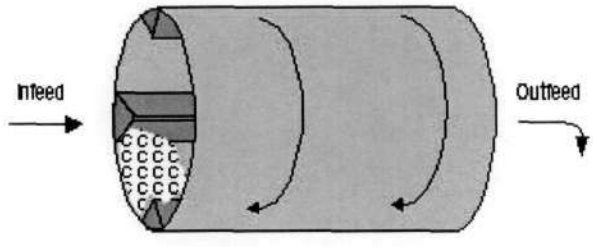

Figure 3.3 Rotating drum

Biological pretreatment serves the purpose of reducing and degrading the biodegradable and organic matter present in the waste body. The technologies used for the pretreatment of MSW include:

Open Windrows

Windrows (Figure 3.4) are elongated piles about 1.5 to 3 metres high and between 3 and 6 metres wide; need to be turned and watered at specific intervals to minimize the occurrence of anaerobic processes within the pile. Open windrows may also be aerated either by suction or pressure principals.

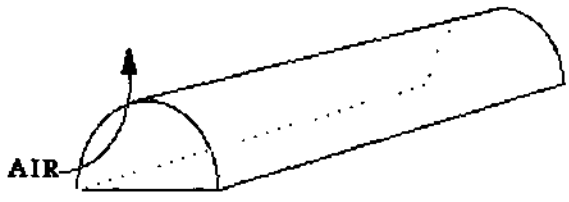

Figure 3.4 Open windrow

Aerated Static Piles

Static piles (Figure 3.5) have a similar shape to windrows elongated pile; however are turned after final construction is complete. Air is drawn through the stationary pile to maintain aerobic conditions and slow degrading substances such as tree branches, wood chippings and structural waste materials are incorporated within the pile to provide air spaces. These spaces supply oxygen to keep processes aerobic and to reduce odours from the pile.

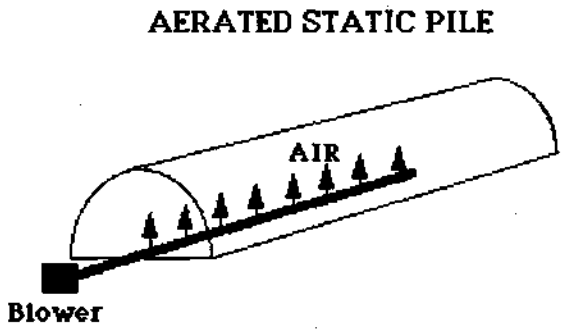

Figure 3.5 Aerated static pile

Drum Systems

Rotating drums (Figure 3.6) about 40 metres long and about 4 metres in diameter are filled with waste and mixed and homogenized; air is supplied to the drum to control the aerobic decomposition process.

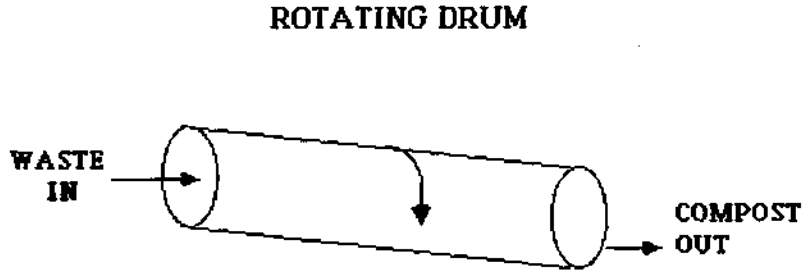

Figure 3.6 Rotating Drum

According to Grey et al (1971) the three major aeration principles that are applied in order to provide oxygen are:

- Waste agitation (turning)
- Forced aeration
- Natural (convective/diffusive) aeration

Large amount of heat energy is produced during aerobic process; this heat energy serves to further enhance the degradation processes and can also be utilized for passive aeration of the material (Krogmann, 1995). During aerobic pretreatment, waste undergoes four degradation stages as showed in Figure 3.7:

- Mesophilic
- Thermophilic
- Cooling
- Maturing

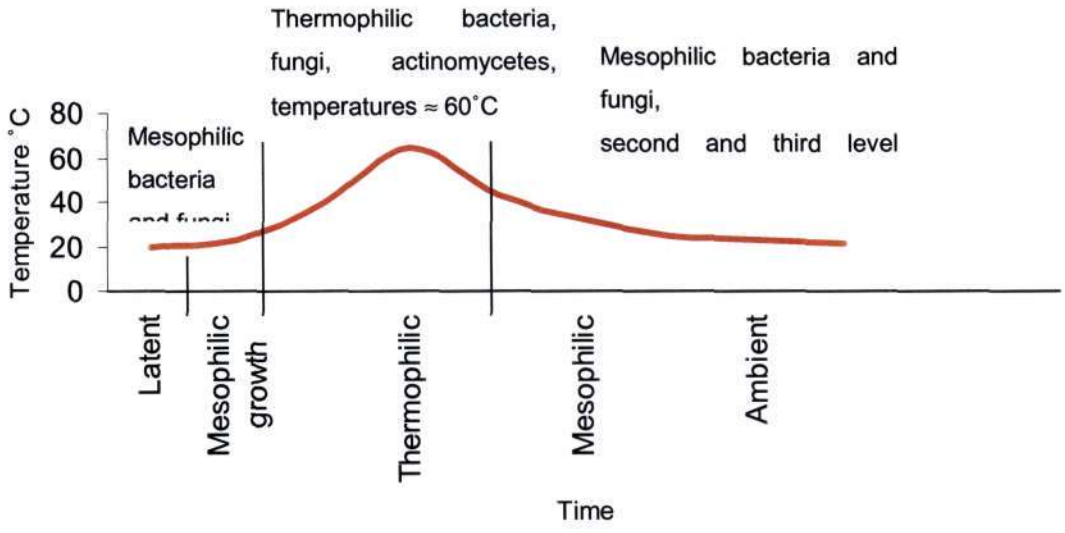

Figure 3.7 Degradation stages during aerobic pre treatment

However, not all of the organic content is biodegradable due to the pressure of resistant molecules, lignin in particular (Haug, 1993).

A factor known as the biodegradable organic fraction (fbi) is applied to the organic carbon content (orgCi) to obtain the total biodegradable organic carbon (orgCbi) (Cossu et. al. 1996).

Thus the biodegradable organic carbon is as follows:

$$orgCbi = orgCi \,.\, fbi\ (1- w\%)\ mi$$

where;

fbi is the biodegradable organic carbon factor

w% is the moisture content of the material i

mi is the total mass of the material i

There are many factors that affect the rate of waste biodegradation which take place under aerobic conditions; biodegrading is dependant on numerous factors such as Oxygen, Carbon-Nitrogen ratio, Moisture, pH, Temperature, Particle size, etc.

Oxygen

The micro-organisms need sufficient air (oxygen) to remain active and to continue under aerobic conditions the biodegradation of the organic matter of the waste. The oxygen requirements are dependant on the type of material (nutrients, particle size), the process temperature, the stage of the process and the process conditions (moisture content, pore structure) (Stentiford, 1996). Shortage of oxygen in the process can develop anaerobic conditions, lower waste degradation rate and also result in the generation of offensive odors and methane (EPA, 1995); the pile should have enough void space to assure the free movement of the air, the supply of oxygen and the removal of CO2 and other gasses. Oxygen concentrations of 10-15% are considered adequate for maintaining aerobic conditions although this value may is as low as 5% for material with a low oxygen demand, such as leaves (EPA, 1995).

Carbon to Nitrogen ratio

Due to the abundance of biodegradable forms of carbon in municipal organics the presence of carbon is not usually a limiting factor in the aerobic degradation processes; however the presence of nitrogen may raise some concerns. The ratio of available carbon to nitrogen of 30-50:1 is considered ideal (EPA, Peavy et al, 1985) higher rations tend to retard the decomposition process while lower rations may result in odor problems caused by the liberation ammonia.

Moisture

The presence of moisture is essential for the microbial activity to take place within the waste material, therefore it is necessary to add water to waste material that has lower than ideal moisture content. However adding excessive water can significantly impede the oxygen transfer to the microorganisms which normally result in the formation of anaerobic areas within the waste and can also lead to leachate generation. Moisture content within the range of 50-60% of total weight is considered to be ideal (Peavy et al, 1985, EPA 1995); some moisture is generated by the microbial processes during the

degradation processes while other quantity is lost into the atmosphere due to evaporation. The rate of evaporation usually exceeds the moisture generated by the microorganisms, resulting in a net loss of moisture from the compose pile. This requires the addition of moisture during the composition period, or initially providing enough moisture for the entire compositing process using larger piles, which have smaller evaporating surfaces, relative to smaller piles, can decrease moisture loss (Griffith, 2005).

pH

The optimum pH range for aerobic degradation is generally between 6 and 8; the pH affects the nutrients available to the microorganisms, the solubility of heavy metals and the overall metabolism of the microorganisms. During the waste degradation, pH is dependant on the input material, on the operating conditions and can be adjusted artificially.

Temperature

The natural aerobic degradation processes that occur within the waste mass generate heat; however the material is generally a poor conductor of heat and therefore the dissipation of this thermal energy is limited resulting in elevated temperatures (Williams, 1998). The optimum temperature range for aerobic degradation is dependent on the design requirements; all microorganisms have an optimal temperature range, and different temperatures result in the dominance of different species of microorganisms, and hence variable degradation outcomes. The temperature range for thermophillic microorganisms is preferred for rapid degradation and destruction of pathogens (Griffith, 2005) The effects of different temperature ranges are shown by the Table 3.2 below:

Table 3.2 The effect of temperature range on aerobic degradation (Stentiford, 1996)

Temperature Range(°C)	Result
>55	Max Sanitation
45-55	Max Biodegradation Rate
35-40	Max Biological Diversity

The pathogen destruction, or sanitization, that occurs within a compost heap, is greater than that reached by thermal destruction only, due to the competition between different microorganism's species (Gray et. al, 1971). The criterions for sanitization for various countries are shown in table 3.3.

Table 3.3 Sanitization requirements for composting in Europe (Stentiford, 1996)

Country	Temperature(°C)	Exposure (Days)
Austria	65	6
Belgium	60	4
Demark	55	14
France	60	4
Italy	55	3
Netherlands	55	2

There are several means of regulating temperature; one way is by adjusting the size of the pile as larger piles generate and conserve more heat than smaller piles while in forced aeration systems, adjusting the airflow affect the heat removal from the pile (Griffith 2005).

Particle size

In aerobic degradation systems the size of the material particles is significant; a smaller particle usually allows for more microbiological activity on the particle surfaces facilitating rapid decomposition. However if the particle sizes are all too small, there is not enough void space to allow the air movement. The material input can be manipulated in order to create an optimum particle size range (EPA, 1995).

3.4 DOME AERATION TECHNOLOGY (DAT)

The Dome Aeration Technology (DAT) was first established in Germany (Mollekopf, 2002), by research initiated at the University of Dresden (Paar, 2000) and the effectiveness was initially tested at the Plauen and Cottbus landfill sites.

The system was later successfully implemented in a larger scale at Cottbus landfill site; this landfill receives approximately 50000 tons of refuse annually (Mollekopf, et.al; 2002).

In South Africa DAT was found to be an appropriate means of waste pretreatment under aerobic conditions in relation to low energy consumption, low construction costs and low input requirements for the duration of the composting period.

For the evaluation of the mechanical-biological pretreatment of waste using the DAT system in South Africa, the city of Durban, situated on the eastern coast of the Republic of South Africa was selected; as it is the largest producer of solid waste in Kwa Zulu Natal.

Three trial windrows were constructed at the Bisasar Road Landfill site and operated by the Durban Solid Waste (DSW); the landfill covers an area of 44 hectares and receives an average of three thousand tons of waste per day with waste composition density between 1.0 t/m^3 and 1.4 t/m^3 (Bowers, 2002), for more information on the Bisasar Road Landfill please refer to Trois et al, 2005.

Intensive research carried out at the Bisasar landfill site demonstrated that full scale DAT can be successfully implemented in South Africa; the use of standard landfilling equipment proved to be successful in the mechanical preparation and subsequent construction of the DAT windrows even though specific machinery would be more efficient in the operations (as available at Cottbus landfill in Germany). Despite of the major concerns which may arose due to the difference between Germany, where the DAT windrow technology was developed and Durban where the windrow trials were to take place, especially regarding climate differences, waste stream differences and equipment limitations, the advantages of being able to utilize the landfills existing plant are significant. It allows smaller landfill sites, particularly in the rural or peri-urban environments, which relay on limited resources, to operate a DAT windrow pretreatment operation with the available machinery, hence reducing capital and operational costs (Trois et al, 2005).

The Dome Aeration Technology (DAT) is a hybrid of open rotting windrows where windrows are constructed such as to facilitate a chimney effect; it promotes the thermal advection and converts the open windrow into a self aerated system where passive aeration is obtained using the natural tendency for warm air to raise as shown in figure 3.8.

Figure 3.8 Natural Air Circulation in a Compost Windrow

Hence the Dome Aeration Technology (DAT) is a passive aeration system, utilizing thermal convection to drive the aeration process within a windrow of waste (Mollekopf et al, 2002).

The structure of a DAT windrow follows a simple concept of using domes and channels to define a path of airflow.

The domes are simple steel bars or mesh and the channels can either be steel or ordinary PVC pipes.

The domes generate hollow spaces inside the windrow, where hot gas accumulates; the geometry of the domes permits the flow of gas from the waste into the dome, but prevents the falling through of solid material (Mollekopf et al., 2002).

A typical windrow is approximately 10 m wide at the bottom, approximately 4 m high, and about 60 m long (although the length is dependent on the available space more than anything else).

The cross-section and plan of a typical windrow is showed in Figure 3.9.

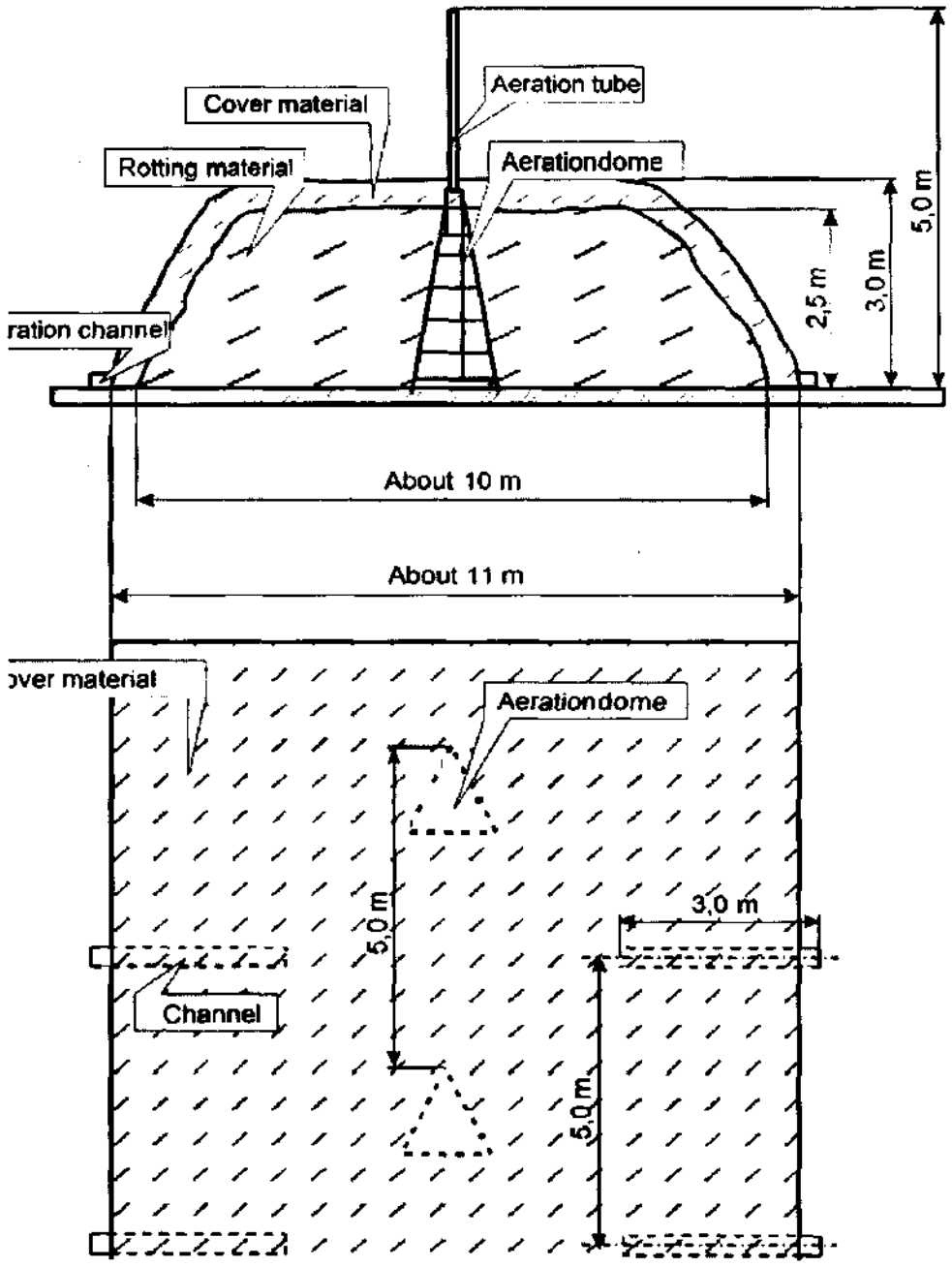

Figure 3.9 The cross-section and plan of a typical windrow (Mollekopf et al, 2002)

As it is indicated in figure 3.10 below the air flows effectively into the aeration channel, passes through the waste material and then flows through the dome by the pressure difference (Soyez, 2003).

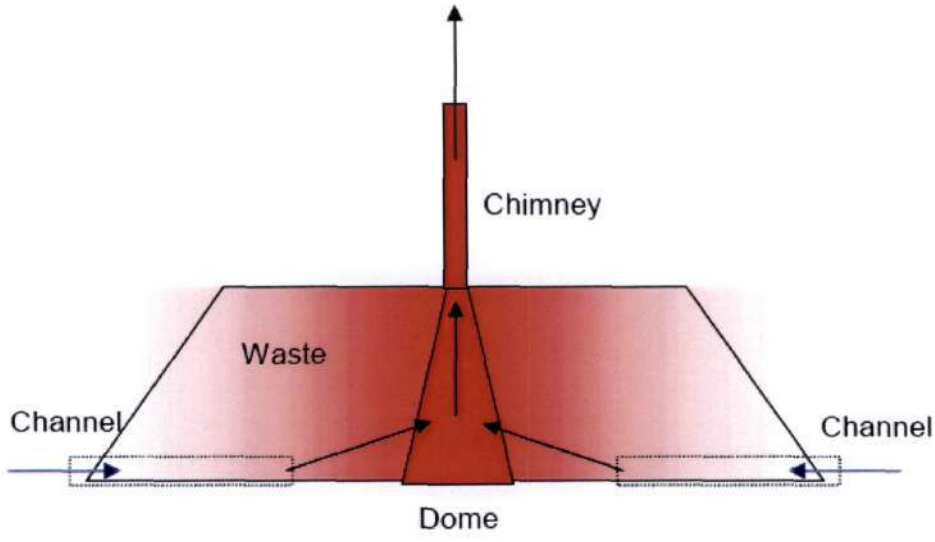

Figure 3.10 Thermal flow of the Dome Aeration Windrow (Griffith, 2005)

Temperature of waste within the windrow can reach 70°C while the ambient temperature is usually less or equal to 30°C.

Open windrows are converted into efficient self aerated systems by the installation of vertical domes and channels in the windrow itself during construction; this particular design help to channel air through the waste material within the windrow.

A large amount of oxygen for the aerobic degradation of waste is provided in this manner.

The airflow is forced due to the temperature gradient present on the outside and inside of the windrow; during aerobic processes, the temperature within the windrow rises, the warm air on the inside rises and at the same time cooler air is drawn from the outside aerating the pile.

The airflow generated by a pressure difference can be described by:

$$\Delta p = \Delta \rho \times g \times h$$ (Mollekopf et al., 2002)

where:

Δp = change in pressure

$\Delta \rho$ = change in density of windrow gas and surrounding air

g = gravitational acceleration

h = height over which the density difference is effective

Chapter 4 : MATERIALS AND METHODS

4.1 INTRODUCTION

Pre-treated waste from the Bisasar Road landfill site (already stated in section 3.4) is leached out in contact with distilled water (leaching medium) so as to establish the capacity of the material to release possible polluted compounds and to define the efficiency of the treatment.

This investigation has the purpose to achieve the following objectives:

- Define the kinetics of the leaching process in an anaerobic environment for different periods of pre-treatment (8 weeks-16 weeks) using leaching columns.
- Assess the effect of grain size on leachate contaminations and biogas production

Leachate and biogas from the 16 weeks pre treated waste columns were monitored for a period of 28 weeks, the 8 weeks pre treated waste columns were investigate for a period of 32 weeks, while the leachate and biogas from fresh waste for 20 weeks.

This discrepancy is due to the availability of the raw material and laboratory equipment.

The investigation was carried out in five clear PVC columns which have also allowed a good visual control of the process.

4.2 COLUMNS SETUP

The columns, placed on a metal structure, are made of a 1m PVC cylindrical body 160mm in diameter, and have a capacity of 20 litres each.

A typical leaching column is showed in Figure 4.1.

Figure 4.10 Leaching column

The upper and lower part of each column is closed with two pairs of 25 mm thick flanges and 280 mm diameter screwed together. The hermetic fit is assured by a rubber gasket (Figure 4.2) with a thickness of 20 mm laid between the flanges.

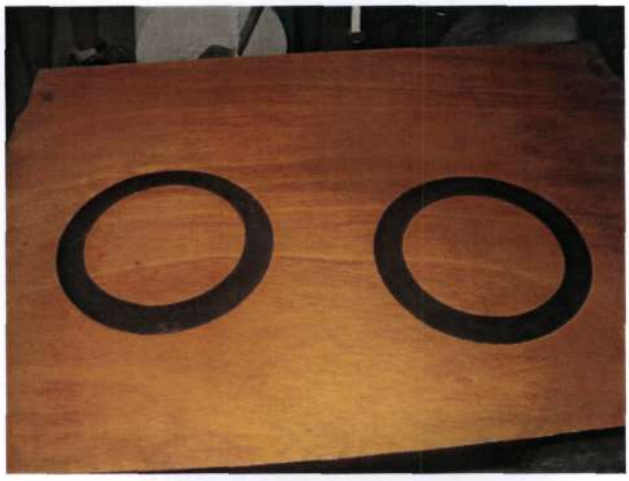

Figure 4.2 Rubber rings

The upper flange has two holes; the first hole is connected to a tap to allow the column to be filled with distilled water while, the second hole is connected to a plastic pipe for biogas measurements. The lower flange has only one hole connected to a pipe with a tap for the collection of leachate (Figure 4.3).

Figure 4.3 Upper and lower flanges

To allow for the leachate extraction and to avoid obstruction of the system by particulate matter, a drainage layer composed of glass marbles of 25 mm diameter was placed at the bottom of each column.

4.3 BIOGAS MEASUREMENT SYSTEM

A biogas measurement system based on liquid displacement method was employed. This system is connected with the top section of the column.

The biogas system is constituted of a 2 liters glass bottle used as a reservoir and by a 1,2 liters graduated glass burette with two taps (respectively used for the connection with the waste column and for reading the biogas collected) filled with a solution (liquid) of sodium chloride (NaCl), and sulphuric acid (H_2S0_4) in order to ensure that none of the biogas components was absorbed (Figure 4.4).

Figure 4.4 Biogas system

Each connection is sealed thoroughly in order to avoid any leakages and is made by means of silicone pipes. Figure 4.5 below illustrates the general functioning of the liquid displacement method.

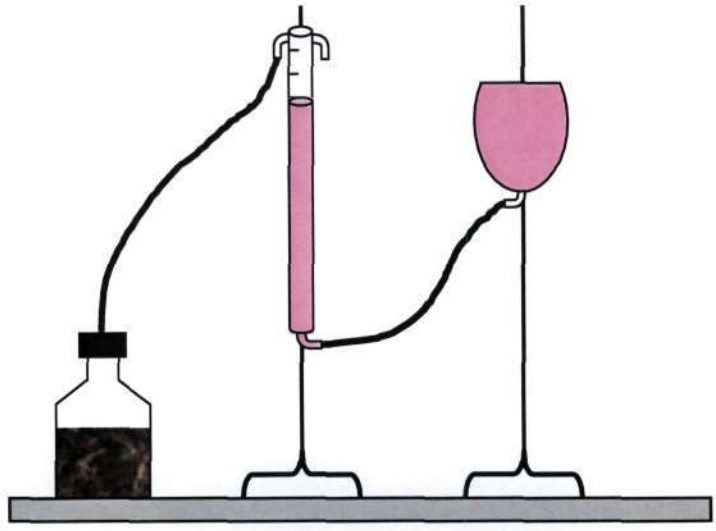

Figure 4.5 General scheme of liquid displacement method

As the biogas from pre-treated waste is produced the liquid in the burette is displaced. The volume of biogas is equivalent to the volume of solution displaced and measured in the graduated burette.

A gas analyzer (GA 2000) was used on a weekly basis to determine the percentage by volume in air of methane (CH_4), carbon dioxide (CO_2) and oxygen (O_2) in biogas. The results of these analyses are reported in the Appendix.

4.4 SAMPLE PREPARATION

In order to understand the degradability of each type of waste, the 16 weeks and 8 weeks pre treated waste samples from DAT windrows obtained from Bisasar landfill site in Durban were divided into three main categories according to their composition.

The three categories are as follows:

- Global sample: waste sample extracted directly from the windrow without sieving.

- Fines or under sieve sample: waste material that passed through 50 mm diameter sieve; this sample has a high content of organic material as it consists mainly of putrescible material.
- Coarse or over sieve sample: waste material that was retained on 50 mm diameter sieve; in contrast with the fines coarse samples has a lower organic material content.

The main reason for grading the waste is to verify and assess the efficiency of the treatment. It should be noted that it is common practice (in the countries that apply MBP) to enhance the treatment efficiency by complying it with at source separation of the high RDF material, the recyclable and the slowly/non biodegradable fraction (as plastic). No separated collection, nor incineration of high RDF, nor any form of MBP is applied in South Africa at present (as explained in Chapter 1), therefore fractioning the global sample in under sieved (>50 mm) and upper sieved (<50 mm) could indirectly provide information on the efficiency of the pilot project and on the most appropriate operational strategies. Figure 4.6 below illustrates the sieving process for the oversized and the undersieve samples.

Figure 4.6 Waste sieving at the Bisasar road landfill site

Also a sample of fresh untreated waste was collected from Bisasar landfill site in Durban and used unsieved to fill the first column. The results of this column were used as control. Quartering was done in order to achieve a true representative of sample.

4.5 COLUMNS OPERATIONS

The columns showed in Figure 4.7 and named as C1, C2, C3, C4, C5, are filled respectively with:

- Column C1 filled with fresh untreated and unsieved waste (fresh global sample),
- Column C2 filled with 16 weeks pre-treated waste $\varphi < 50$ mm (fine),
- Column C3 filled with 16 weeks pre-treated waste $\varphi > 50$ mm (coarse),
- Column C4 filled with 8 weeks pre-treated waste $\varphi < 50$ mm (fine),
- Column C5 filled with 8 weeks pre-treated waste $\varphi > 50$ mm (coarse).

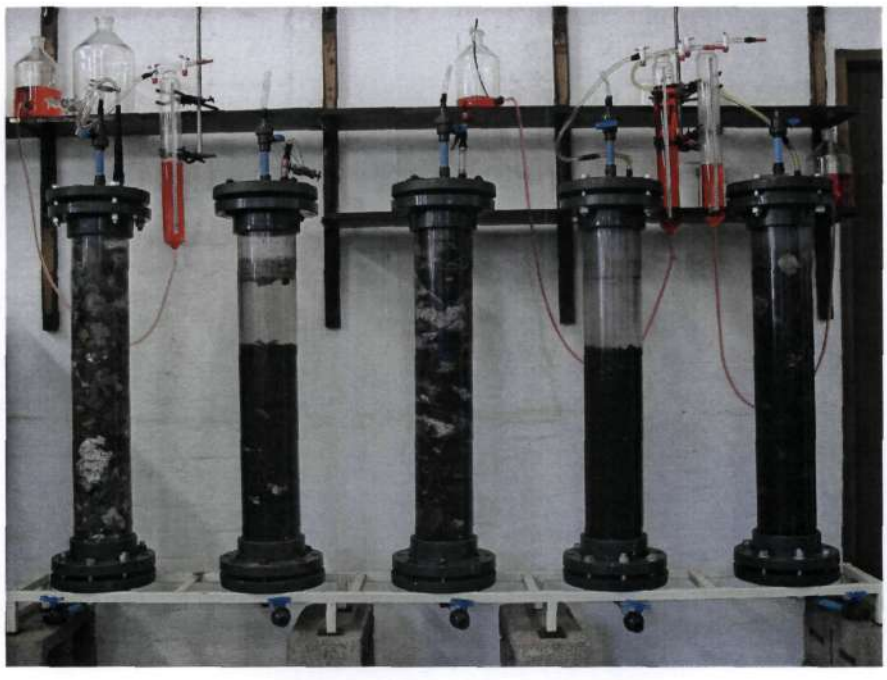

Figure 4.7 Leaching columns (from left to right, Columns 1, 2, 3, 4, 5)

The liquid in the columns was drained once a week and collected at the bottom of the system. The collected leachate was weighed and stored in a fridge at 4°C for analysis. Before emptying the column a gas analyser (Figure 4.8) was used to analyse the composition of the gas collected in the graduated glass burette connected to the column. Percentage of CH_4, CO_2 and O_2 were determined and recorded.

Figure 4.8 Gas analyser

Immediately after drainage the columns were refilled with a quantity of de-oxygenated distilled water equal to the leachate previously collected.

The columns were irrigated with distilled water to allow for a fixed 7-day water-waste contact period. Distilled water is used in leaching tests to simulate rainfall events, because its pH is similar to that of natural rainfall (5.5-7.5) while its negligible saline content maximises the transport between solid and liquid phase (Trois et al., 2006) The aim of this process is to estimate the evolution of the release of polluted compounds in a certain period of time. The amount of water used to fill each column is determined with a different Liquid/Solid initial ratio (litres of distilled water per 1Kg of dry matter). The following Table 4.1 shows the starting conditions for each column.

Table 4.1 Starting conditions for each column

COLUMN INPUT (in Kg)	C1 Fresh waste	C2 16 wks fine	C3 16 wks coarse	C4 8 wks fine	C5 8 wks coarse
Total Input Mass	8.52	6.21	1.80	7.55	3.34
Moisture Input	3.57	0.88	0.17	1.36	0.70
Dry Mass	4.95	5.33	1.62	6.19	2.64
Added Water	6.00	9.26	12.00	10.48	9.67
Total Moisture	9.57	10.14	12.17	11.83	10.37
L/S Ratio	1.93	1.90	7.50	1.91	3.93

Total input mass = Moisture Input + Dry mass

Total moisture = Moisture Input + Added water

L/S ratio = Total moisture / Dry mass

Each column was filled with different amount of input material with an internal column space occupation of 15 litres; approximately 5 litres of airspace were left in each column.

4.6 WASTE CHARACTERIZATION

The input and output material to each column were characterized using composition of the input material (presented in Chapter 5, Table 5.1), solid matter (referred to Dry Mass in Table 4.1 above) and eluate tests. The eluate test allows for the determination of soluble organic and inorganic components leached out from the waste matrix in 24 or 72 hours. A representative sample of the material is mixed to distilled water in a liquid to solid ratio of 10/1 and shaken for 24 hours (Figure 4.9).

Figure 4.9 Sample on a stirrer

The eluate is then filtered using a Whatman 40 filter paper (Figure 4.10) and the filtered leachate analyzed for the following parameters: COD, BOD, NH_3, NOx, pH, Conductivity, Solids and Moisture content.

Figure 4.10 Filtration to obtain an eluate

4.7 LEACHATE ANALYSIS

The study of the leaching processes of pre treated waste aims at understanding the capacity of the material to release possible polluting compounds and to confirm the efficiency of the pre treatment itself. The COD value clearly shows the reduction of polluting compounds in the examined samples. Moreover the reductions in levels of NH3 and NOx were measured. In order to control the treatment process, the measurement of pH, conductivity, temperature, and solids are also important while metals and pathogenic elements were not analyzed and discussed in this dissertation. The results were obtained through the use of standard analytical methods; as described by standard test procedures published by ASTM (Clesceri et al, 1989). All the analyses were conducted in the Environmental Engineering laboratory at the University of Kwa-Zulu Natal, Durban, South Africa.

4.7.1 Temperature

The temperature of the leachate was recorded once a week before taking samples, through the use of an MT digital thermometer.

4.7.2 pH

The measuring of pH was carried out once a week using an Orion pH meter.

4.7.3 Conductivity

The conductivity of a solution gives an indication of the amount of dissolved ionic compounds and the total dissolved solids. Conductivity tests were carried out once a week using a Corning conductivity meter.

The pH and Conductivity measurement device are shown in Figure 4.11

Figure 4.11 pH and conductivity meter

4.7.4 Chemical Oxygen Demand (COD)

The COD test procedure follows the ASTM standard method number 5220, (1990), using the closed reflux method. The Chemical Oxygen Demand (COD) is a measurement of the amount of oxygen that is required for the chemical oxidation of the organic matter contained in waste water. A sample of leachate is added to a solution of potassium dichromate ($K_2Cr_2O_7$) as oxiding agent with sulphuric acid (H_2SO_4).

The samples are digested for two hours at 180°C and then condensed; the dichromate remaining in each sample mixture is titrated with a standard ferrous ammonium sulphate (FAS) using a ferroin indicator that generates a change from orange to blue-green through to dark brown.

The consumption of effective oxidant which is expressed in terms of oxygen equivalent with the formula:

$$COD\ mgO_2 = [(A - B) \cdot N \cdot 8000] / V$$

where:

A = ml of titrant used in the blank sample

B = ml of titrant used in the sample

N = normality of the titrant

V = volume of leachate sample

The 8000 multiplier is used to express results in units of milligrams per litre of oxygen, since 1 litre contains 1000 ml and the equivalent weigh of oxygen is 8.

4.7.5 Ammoniacal-Nitrogen (NH_3-N or NH_4-N)

The ammonia test procedure follows the ASTM standard method number D1426 (Clesceri et al, 1989).

The ammonia nitrogen (NH_3) exists in aqueous form and as an ion of ammonia; (ammoniacal nitrogen NH_4^+) depending on the pH of the solution in connection with the following equilibrium reaction equation:

$$NH_3 + H_2O = NH_4^+ + OH^-$$

At pH 7 the ammonium ion (NH_4^+) exists in solution while at pH 12 the solution contains NH_3 as a dissolved gas.

After a first steam out to clean the apparatus, the sample of leachate is placed in a glass tube and attached to a steam distillation apparatus. Sodium hydroxide is added, the sample is distilled and the steam is condensed and collected in a flask containing a solution of boric acid. The distilled solution in the flask turns from a deep purple to a bright green; the concentration of ammonia (NH_3) is then determined by titration of the distillate. The determination of nitrates (NOx) is carried out using the residual sample in the tube; magnesium oxide and Devardas alloy are added to the sample and a new flask

with the solution of boric acid is replaced and after being steamed, is titrated as above. The apparatus and the ammonia sample are showed in Figure 4.12 and 4.13.

Figure 4.12 Ammonia distiller apparatus

Figure 4.13 Sample for the ammoniacal nitrogen and nitrates analysis

4.7.6 Total Solids (TS) / Volatile Solids (VS)

The measurement of the Total Solids (TS) is the quantity of total residue remaining after a sample has evaporated in a drying oven at 110◦C. This sample is then placed in a furnace at a temperature between 500 and 600◦C, where the volatile components of the sample are released (VS). The equations of TS and VS are as follows:

$$TS\ g/l = [(W_{TS} - W_D) \times 1000] / V_S$$

$$FS\ g/l = [W_{FS} - W_D) \times 1000] / V_S$$

and therefore:

$$VS\ g/l = TS - FS$$

where:

W_D = mass of the dish (g),

W_{TS} = mass of the dried residue in the dish (g),

W_{FS} = mass of the fixed solids remaining in the dish after combustion (g),

V_S = volume of the sample (l),

FS = concentration of non-volatile fixed solids (mg/l),

1000 = multiple to convert the concentrations in g/l.

The drying oven and the furnace used in the determination of TS and VS are showed in Figure 4.14 and 4.15 respectively.

Figure 4.14 Drying oven

Figure 4.1 Furnace

4.8 ACCURACY TESTING

All the analyses listed before were carried out in triplicate. The results presented in Chapter 5 are an average of the measured values; the raw data are presented in the Appendix. For each set of data, media, standard deviation and variation were calculated and an example of these calculations for TS, VS, COD, NH3, NOx is reported below in Table 4.2, 4.3 and 4.4.

Table 4.2 Total Solids and Volatile Solids

DATE	WEEK		RAW DATA			AVE	STDEV	VAR
			COLUMN 1					
27-Jun-06	6	TS	4.58	4.31	4.06	4.32	0.26	0.07
"	"	VS	2.36	2.58	2.30	2.42	0.15	0.02
22-Aug-06	14	TS	4.32	4.28	4.24	4.28	0.04	0.00
"	"	VS	2.22	2.23	2.19	2.21	0.02	0.00
26-Sep-06	19	TS	2.71	2.09	2.28	2.36	0.32	0.10
"	"	VS	1.76	1.34	1.34	1.48	0.24	0.06
			COLUMN 2					
2-Feb-06	20	TS	0.41	0.40	0.34	0.39	0.04	0.00
"	"	VS	0.22	0.20	0.22	0.21	0.01	0.00
6-Mar-06	24	TS	0.99	0.52	0.50	0.67	0.28	0.08
"	"	VS	0.70	0.34	0.34	0.46	0.21	0.04
16-Mar-06	26	TS	0.42	0.41	0.42	0.42	0.01	0.00
"	"	VS	0.29	0.29	0.32	0.30	0.02	0.00
			COLUMN 3					
11-Jan-06	18	TS	0.20	0.18	0.16	0.18	0.02	0.00
"	"	VS	0.10	0.12	0.13	0.12	0.02	0.00
2-Feb-06	20	TS	0.29	0.27	0.24	0.27	0.02	0.00
"	"	VS	0.09	0.06	0.01	0.05	0.04	0.00
6-Mar-06	24	TS	0.27	0.22	0.28	0.25	0.03	0.00
"	"	VS	0.12	0.04	0.12	0.09	0.05	0.00
			COLUMN 4					
11-Jan-06	5	TS	1.62	1.61	1.62	1.62	0.01	0.00
"	"	VS	0.96	0.96	0.97	0.96	0.01	0.00
2-Feb-06	7	TS	1.10	1.08	1.05	1.07	0.03	0.00
"	"	VS	0.71	0.68	0.68	0.69	0.02	0.00
6-Mar-06	11	TS	0.74	0.75	0.68	0.72	0.04	0.00
"	"	VS	0.52	0.51	0.47	0.50	0.03	0.00
			COLUMN 5					
11-Jan-06	5	TS	1.44	1.42	1.45	1.43	0.02	0.00
"	"	VS	0.82	0.79	0.80	0.80	0.02	0.00
16-Mar-06	11	TS	0.58	0.56	0.62	0.59	0.03	0.00
"	"	VS	0.41	0.41	0.48	0.43	0.04	0.00
13-Jun-06	25	TS	0.20	0.24	0.22	0.22	0.02	0.00
"	"	VS	0.09	0.11	0.16	0.12	0.03	0.00

Table 4.3 COD

DATE	WEEK	RAW DATA			AVE	STDEV	VAR	RESULT
		COLUMN 1						COD
4-Jul-06	7	0.130	0.134	0.134	0.133	0.002	0.000	13555.63
8-Aug-06	12	0.094	0.093	0.100	0.096	0.004	0.000	9644.53
3-Oct-06	18	0.103	0.104	0.102	0.103	0.001	0.000	6232.32
		COLUMN 2						
16-Feb-06	22	0.026	0.026	0.026	0.026	0.000	0.000	62.72
6-Mar-06	24	0.033	0.032	0.033	0.033	0.001	0.000	80.87
16-Mar-06	26	0.032	0.032	0.031	0.032	0.001	0.000	76.74
		COLUMN 3						
16-Feb-06	22	0.031	0.029	0.026	0.029	0.003	0.000	69.32
6-Mar-06	24	0.033	0.031	0.03	0.031	0.002	0.000	77.57
16-Mar-06	26	0.026	0.024	0.026	0.025	0.001	0.000	61.06
		COLUMN 4						
16-Feb-06	9	0.069	0.072	0.066	0.069	0.003	0.000	169.17
6-Mar-06	11	0.053	0.055	0.056	0.055	0.002	0.000	135.33
2-May-06	19	0.035	0.036	0.035	0.035	0.001	0.000	82.52
		COLUMN 5						
16-Feb-06	9	0.096	0.094	0.093	0.094	0.002	0.000	231.88
6-Mar-06	11	0.063	0.063	0.064	0.063	0.00	0.00	156.79
2-May-06	19	0.028	0.028	0.028	0.028	0.00	0.00	64.37

Table 4.4 NH_3 and NO_x

DATE	WEEK		RAW DATA			AVE	STDEV	VAR	RESULTS
			COLUMN 1						
27-Jun-06	6	NH_3	8.22	10.17	10.18	9.52	1.13	1.27	284.90
"	"	NO_x	0.33	0.19	0.22	0.25	0.07	0.01	5.74
5-Sep-06	16	NH_3	2.42	2.29	2.36	2.36	0.07	0.00	65.94
"	"	NO_x	0.23	0.17	0.20	0.20	0.03	0.00	5.60
26-Sep-06	19	NH_3	1.65	2.06	1.64	1.78	0.24	0.06	49.93
"	"	NO_x	0.22	0.20	0.18	0.20	0.02	0.00	5.60
			COLUMN 2						
16-Feb-06	22	NH_3	0.17	0.18	0.18	0.18	0.01	0.00	2.47
"	"	NO_x	0.26	0.42	0.31	0.33	0.08	0.01	4.62
6-Mar-06	24	NH_3	0.35	0.31	0.32	0.33	0.02	0.00	4.57
"	"	NO_x	0.22	0.52	0.51	0.42	0.17	0.03	5.83
16-Mar-06	26	NH_3	0.23	0.22	0.23	0.23	0.01	0.00	3.15
"	"	NO_x	0.33	0.34	0.34	0.34	0.01	0.00	4.69
			COLUMN 3						
16-Feb-06	22	NH_3	0.05	0.05	0.04	0.05	0.01	0.00	0.65
"	"	NO_x	0.41	0.31	0.38	0.37	0.05	0.00	5.13
6-Mar-06	24	NH_3	0.13	0.14	0.11	0.13	0.02	0.00	1.77
"	"	NO_x	0.27	0.23	0.25	0.25	0.02	0.00	3.50
16-Mar-06	26	NH_3	0.10	0.12	0.11	0.11	0.01	0.00	1.54
"	"	NO_x	0.42	0.44	0.43	0.43	0.01	0.00	6.02
			COLUMN C4						
16-Feb-06	9	NH_3	0.58	0.56	0.59	0.58	0.02	0.00	16.10
"	"	NO_x	0.21	0.26	0.40	0.29	0.10	0.01	8.12
6-Mar-06	11	NH_3	0.64	0.61	0.63	0.63	0.02	0.00	17.55
"	"	NO_x	0.48	0.55	0.69	0.57	0.11	0.01	16.05
2-May-06	19	NH_3	0.33	0.30	0.32	0.32	0.02	0.00	8.82
"	"	NO_x	0.67	0.68	0.68	0.68	0.01	0.00	18.90
			COLUMN 5						
16-Feb-06	9	NH_3	0.12	0.09	0.12	0.11	0.02	0.00	3.08
"	"	NO_x	0.32	0.36	0.50	0.39	0.09	0.01	11.01
6-Mar-06	11	NH_3	0.13	0.20	0.19	0.17	0.04	0.00	4.85
"	"	NO_x	0.61	0.35	0.37	0.44	0.14	0.02	12.41
2-May-06	19	NH_3	0.15	0.14	0.15	0.15	0.01	0.00	4.06
"	"	NO_x	0.53	0.55	0.54	0.54	0.01	0.00	15.12

AVE = average, STDEV = standard deviation, VAR = coefficient of variation (%)

The standard deviations of the data from the triplicates samples were calculated using the following equation, taken from Clesceri et al (1989).

$$S_D = \frac{\overline{R}}{1.128}$$

where

S_D = standard deviation for duplicates and the average range $\overline{R}$ is:

$$\overline{R} = \frac{\sum |differences|}{n_o}$$

where

n_0 = number of observations.

The standard deviation of the data from the multiple analyses of a single sample was calculated using the following equation (Robertson et al, 1995).

$$S_M = \sqrt{\frac{\sum_{Z=1}^{n} (C_Z - \overline{C})^2}{n_o - 1}}$$

where

S_M = standard deviation for multiple analyses of a single sample,

C_Z = concentration of sample z.

and

$$\overline{C} = \frac{\sum_{Z=1}^{n} C_Z}{n_o}.$$

The precision tests conducted on the triplicate samples showed a high level of precision with a standard deviation below that specified by the Clesceri et al (1989).

Chapter 5 : RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

The leaching process that can occur in the landfill during the infiltration of rainfall that forms leachate was studied in the columns in relation to the following:

- Degree of pre treatment: untreated waste, 16 weeks and 8 weeks pre treated waste.
- Grain size distribution

The results of the analysis for both 16 weeks and 8 weeks pre treated waste columns together with fresh waste column are presented in this chapter.

5.2 WASTE COMPOSITIONS

The composition of the input material into the columns is presented in Table 5.1 below.

Table 5.1 Waste composition of input material

Component (% mass)	untreated waste	treated waste global	treated waste fine	treated waste coarse
Plastics	31	14.6	2.5	26.6
Fines	22	31	54.5	7.6
Paper	25	13.1	6.3	19.7
Fabric	4	13.6	1.2	25.3
Glass	7	4.2	7.7	0.8
Metal	6	2.8	0.8	4.6
Wood	0	3.9	0	7.4
Rubber	5	3.5	0	3.8
Stones	0	7.7	11.5	4.2
Plant matter	0	15.1	15.1	0
Bone	0	0	0.3	0

The different components percentages of the 4 global samples are presented in Figure 5.1, 5.2, 5.3 and 5.4.

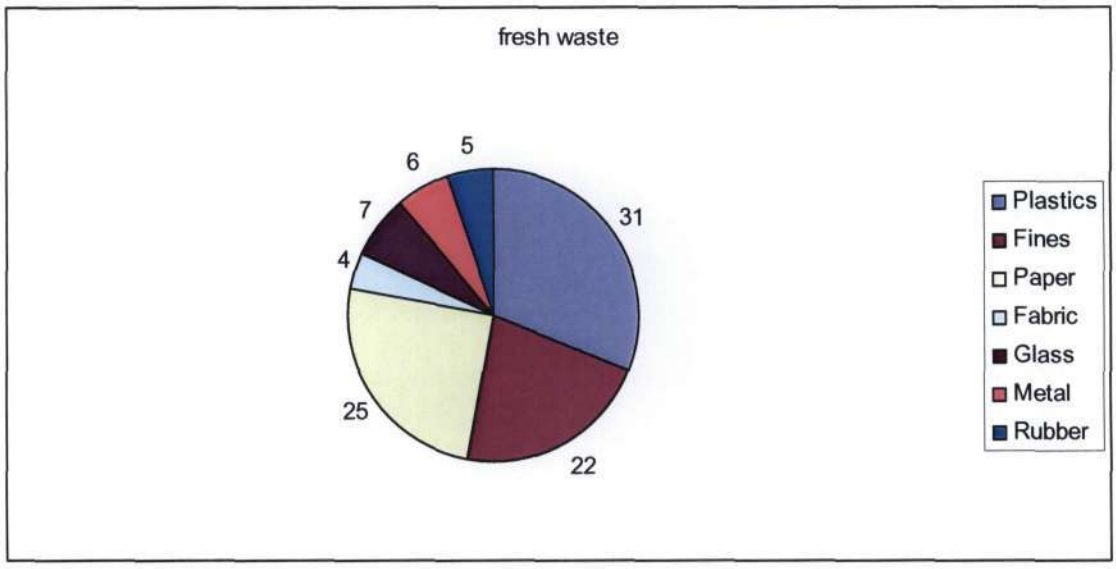

Figure 5.1 Components percentages of fresh waste sample

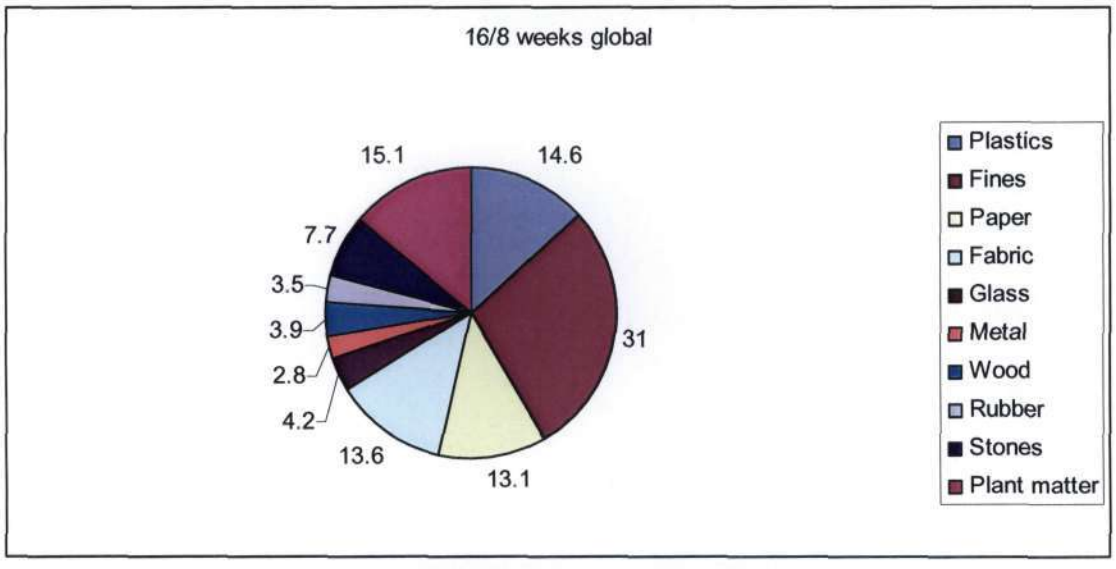

Figure 5.2 Components percentages of 16/8 weeks pre treated waste global sample

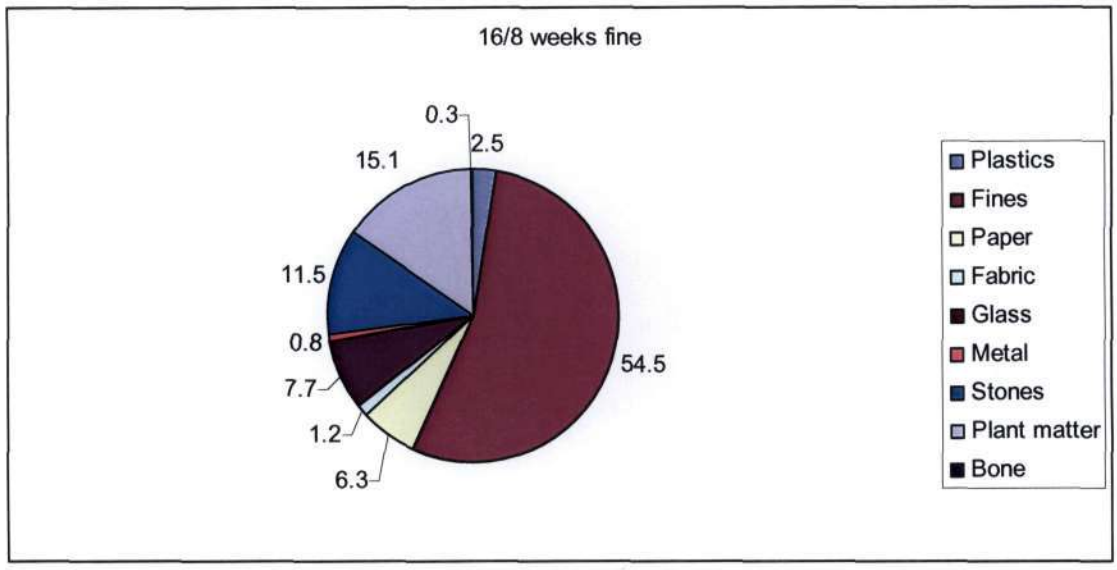

Figure 5.3 Components percentages of 16/8 weeks pre treated waste fine sample

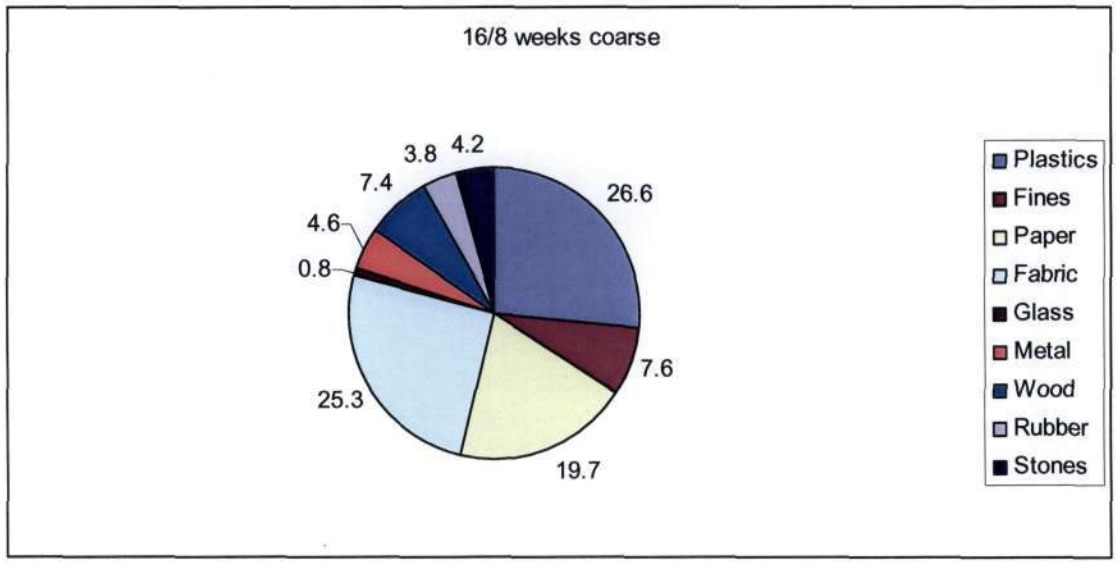

Figure 5.4 Components percentages of 16/8 weeks pre treated waste coarse sample

5.3 CHARACTERIZATION OF WASTE

5.3.1 Analysis on the eluates

The Table 5.2 shows the results of the eluates tests on the input material and also a comparison with some European standards for the disposal of MBP materials into landfills (Munnich et al., 2005).

Table 5.2 Results of eluate tests on the input material

DETERMINAND 24 hours test	COLUMN 1 fresh waste	COLUMN 2 16 wks fine	COLUMN 3 16 wks coarse	COLUMN 4 8 wks fine	COLUMN 5 8 wks coarse	EUROPEAN STANDARD
pH	5.29	7.32	7.04	7.34	6.86	5.5 - 13.0
Conductivity (mS/cm)	6.20	1.41	1.84	1534.50	1713.50	<50
Ammonical-N (N mg/l)	48.49	27.32	23.30	14.85	11.13	<250
Nitrates (N mg/l)	18.15	4.93	5.90	8.61	7.42	
TKN (mg/l)	13.00	83.00	69.00	83.00	69.00	
Total Solids (g/l)	15.62	7.31	5.12	0.11	0.08	
Volatile Solids (g/l)	7.13	2.62	2.80	0.06	0.06	
COD (mg/l)	7598.72	3206.00	3675.00	1489.49	1489.49	
TOC (mg/l)	46.00	538.00	536.00	538.00	536.00	<250

Some parameters, as NH_4 - N shows measured concentrations below the European limits while, for example TOC values do not comply with the standards limits.

5.4 COLUMNS MONITORING

5.4.1 Biogas testing

The gas production and the evolution of the gas composition within the columns are illustrated in Figures 5.5, 5.6, 5.7, 5.8 and 5.9. A more detailed analysis of the gas production can be seen in the Appendix.

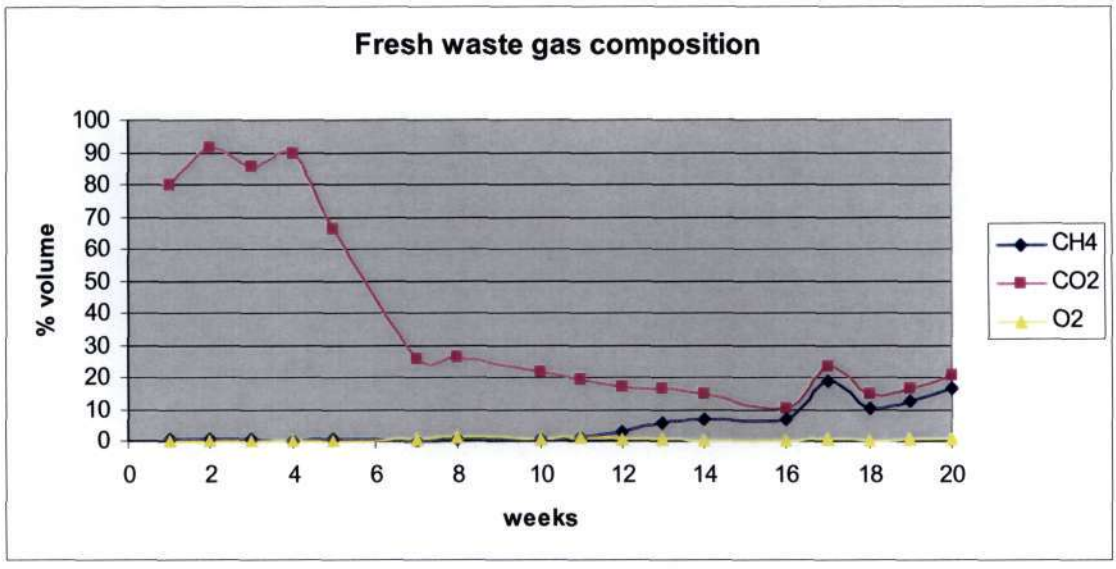

Figure 5.5 Evolution of gas composition in Column 1

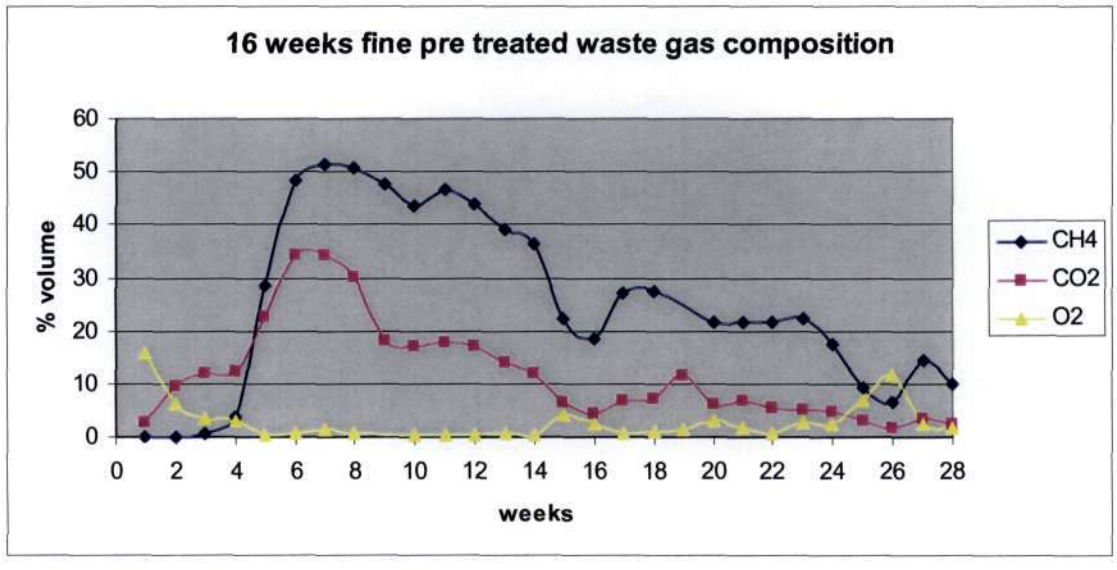

Figure 5.6 Evolution of gas composition in Column 2

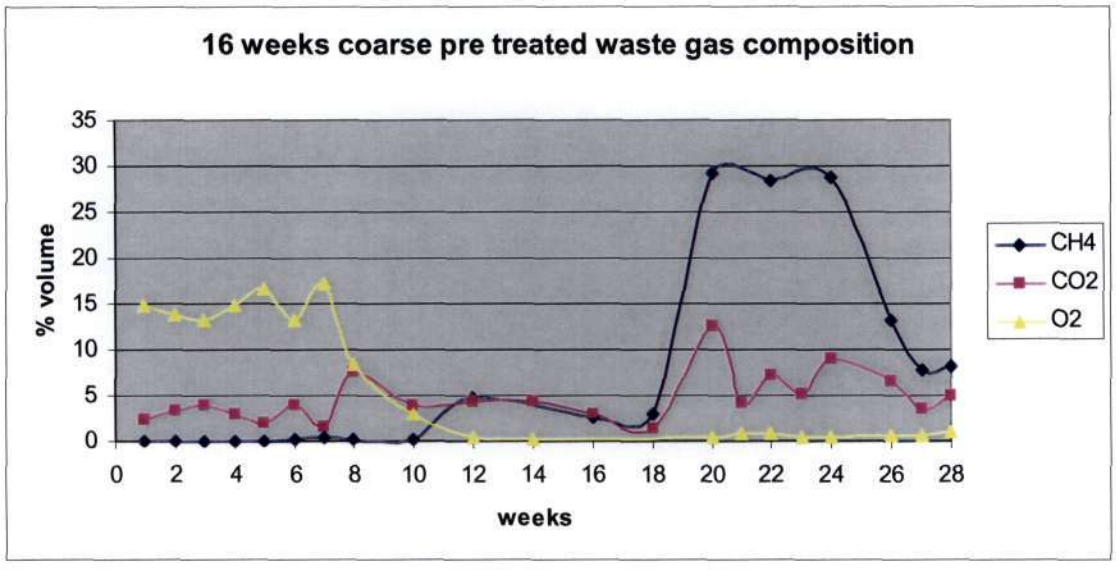

Figure 5.7 Evolution of gas composition in Column 3

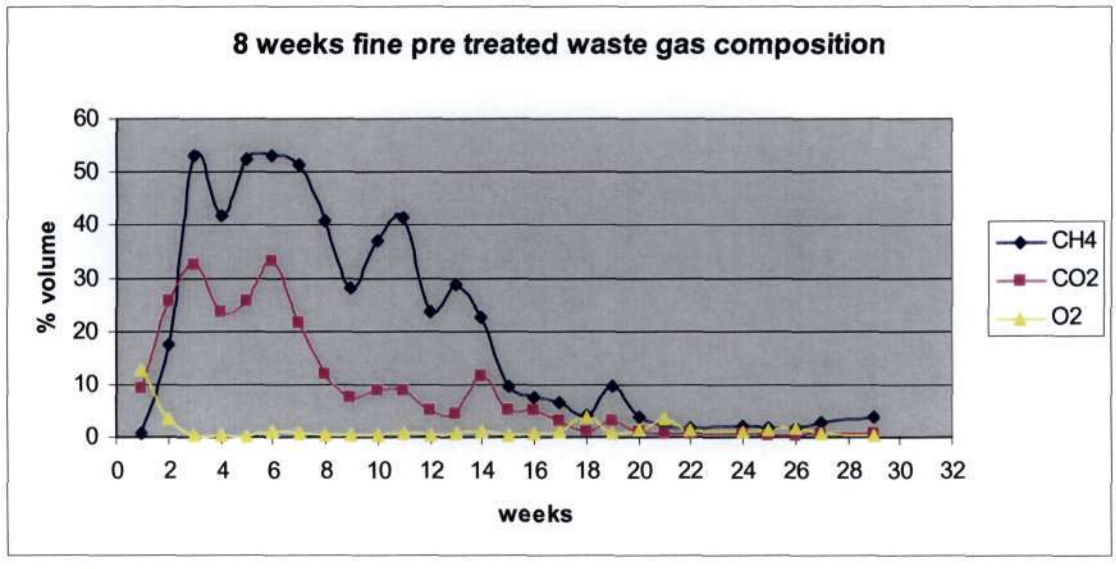

Figure 5.8 Evolution of gas composition in Column 4

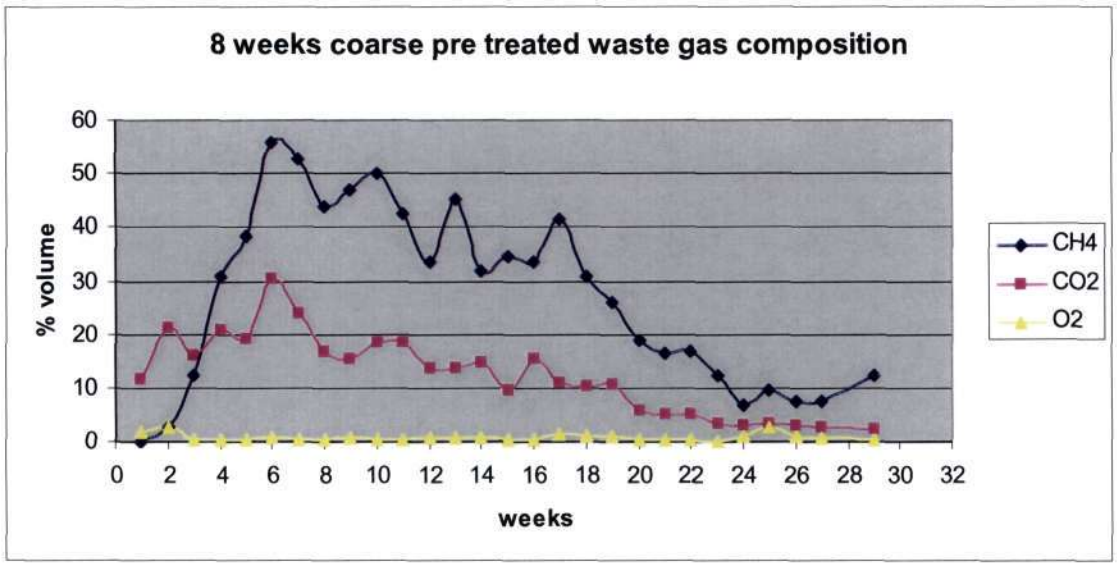

Figure 5.9 Evolution of gas composition in Column 5

At the beginning of the leaching campaign the initial air space within the columns above the waste is saturated with a very high oxygen level inside; the deoxygenated water introduced into the columns on a weekly basis has reduced the amount of oxygen but a semi anaerobic condition is being established only after the third week when oxygen levels has began to drop consistently. After the organic compounds are being degraded, CO2 is consumed and methane production is being found at this stage. The produced gases are been displaced very slowly within the column bodies and only at this stage an anaerobic condition occurs. These processes have helped to reduce the oxygen levels within the columns with good results; however only in column 3 (16 weeks coarse) no significant decrease in the oxygen levels is being noted until 10 weeks of study. In Column 1 (fresh waste), after twenty weeks the presence of carbon dioxide is still high while the level of methane is slowly rising due to the presence of organic compounds not already degraded. After few weeks of semi anaerobic conditions, methane within Column 2 (16 weeks fine) increases to 50%, then fluctuates between 50% and 30% and decreases to 10% as the leaching process proceeds. 18 weeks were necessary to reach full anaerobic conditions and the low levels of methane gas formed are most likely due to the limited amount of organic compound availablenin the waste matrix. The methane production of 8 weeks pretreated waste fine and coarse fraction occurred in the same timeframe. This possibly implies that a better sieving of the material would have reduced the percentage of fines into the upper sieve fraction. The high content of CO2 for 8

weeks pretreated waste fine and coarse fraction may have saturated the water with HCO3, contributing to lowering the pH together with the initial formation of acids. The methanogenic phase occurs much earlier for the 8 weeks than 16 weeks pre treated waste while fresh waste in the same time scale is still in acidogenic phase. The high rate of leaching is evident especially if compared with COD removal.

5.5 LEACHATE ANALYSIS

Two main processes occur in the waste body within the columns; the leaching of water through the waste to promote the physical removal of contaminants while aerobic or anaerobic conditions involve biological processes and biological degradation of the waste fraction.

5.5.1 pH

Figures 5.10, 5.11, 5.12, 5.13 and 5.14 show the pH leachate analysis trend for the five columns.

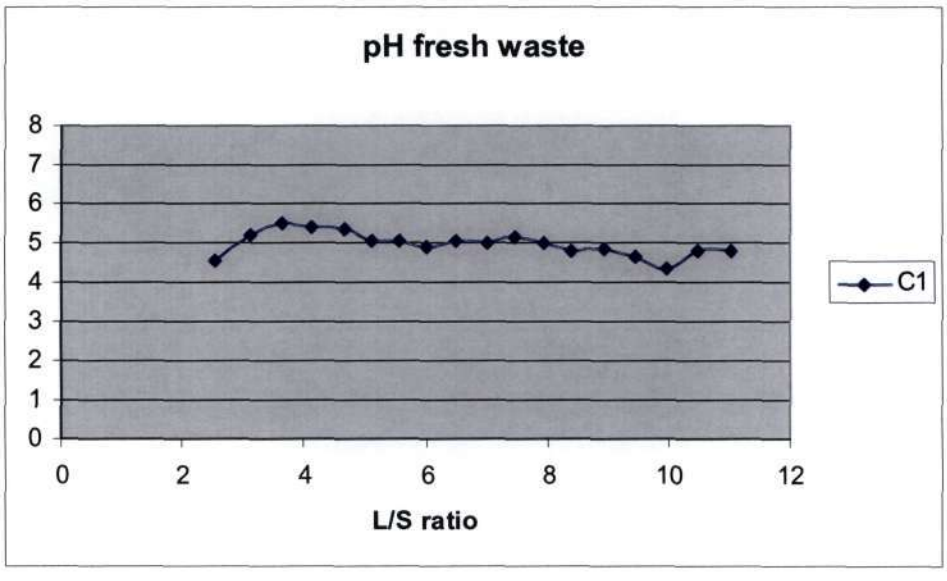

Figure 5.10 Fresh waste pH

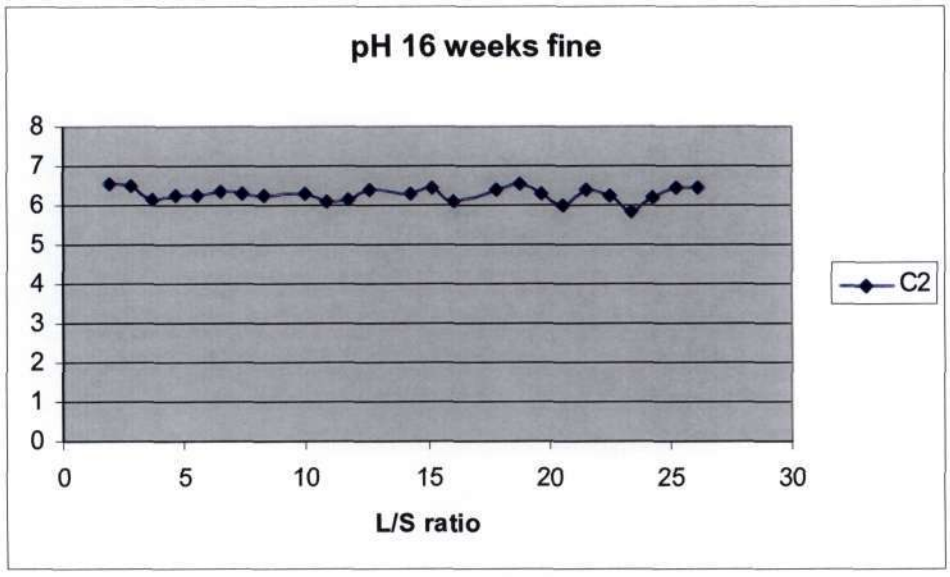

Figure 5.11 16 weeks fine pH

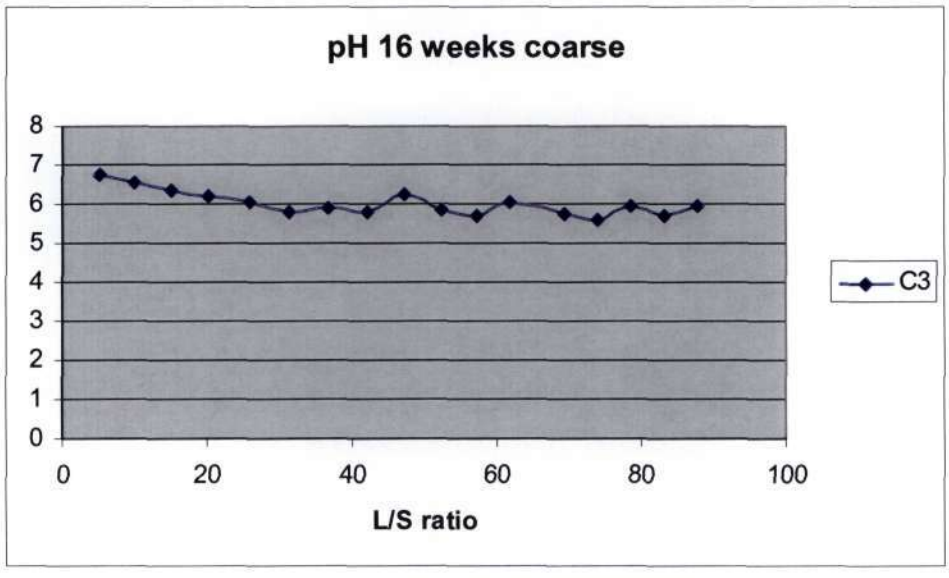

Figure 5.12 16 weeks coarse pH

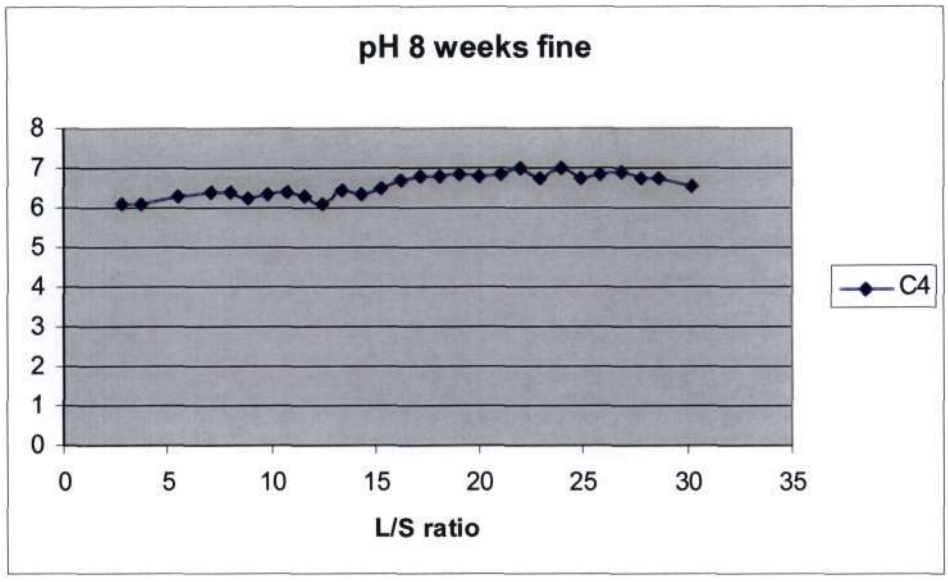

Figure 5.13 8 weeks fine pH

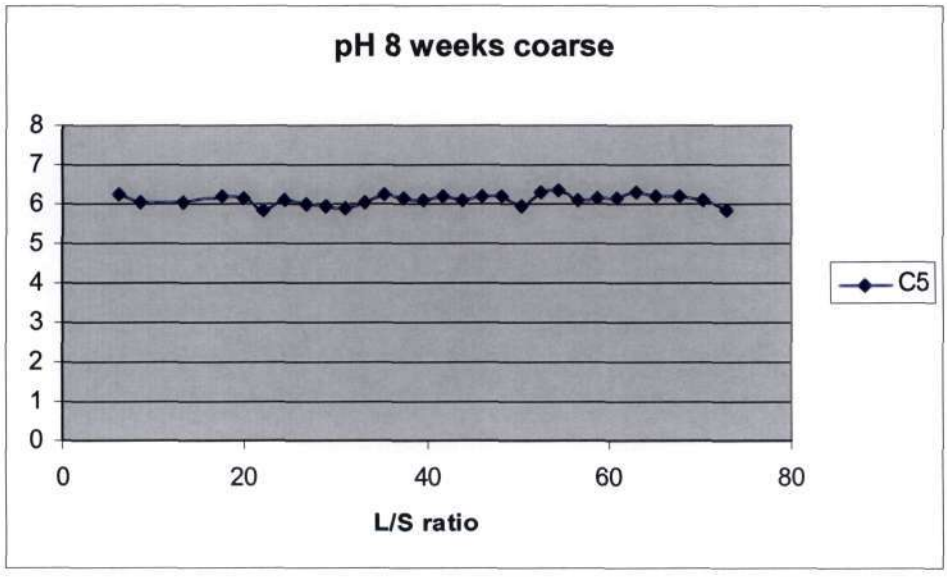

Figure 5.14 8 weeks coarse pH

For the entire testing period, distilled water at pH 7.2 is being used as leaching agent; this could indicate a neutral to slightly basic solution into the columns. For this reason, the leachate produced from the columns filled with pre treated waste was expected to have a pH of neutral nature as the leaching agent is, also in connection with the neutral nature of the pre treated waste body which should not show acidic pH ranges due to the limited acidogenic and acetogenic phases experienced. The weekly leachate analysis

showed that the pH values of Columns 2 to 5 being slightly acidic. In fact the pH range for Column 2 is between 6.56 and 5.85, for Column 3 is between 6.77 and 5.61 and for Column 5 is between 6.37 and 5.84. The pH values for Column 1 (fresh waste) range around 5.52 and 4.37. The pH values range for Column 4 is between 7.02 to 6.09. The presence of carbon dioxide (CO_2) can explain the acidic pH within the columns. The high concentrations of CO_2 solubilized in water promote the formation of HCO_3; the reaction of CO_2 and water produces carbonic acid which leads to an increase in acids correlate to a decrease in pH levels.

5.5.2 Conductivity

Figures 5.15, 5.16, 5.17, 5.18 and 5.19 show the conductivity trend for the five columns.

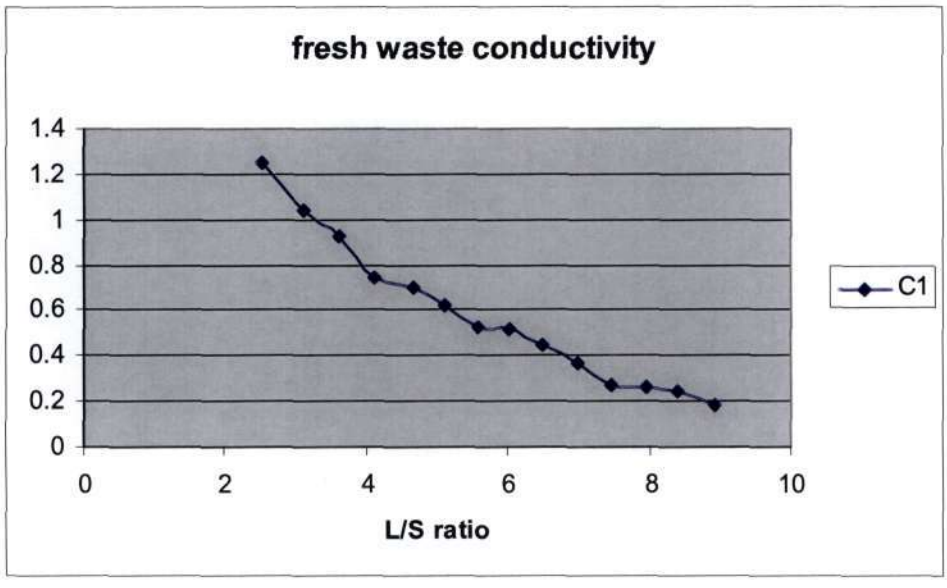

Figure 5.15 Conductivity for fresh waste

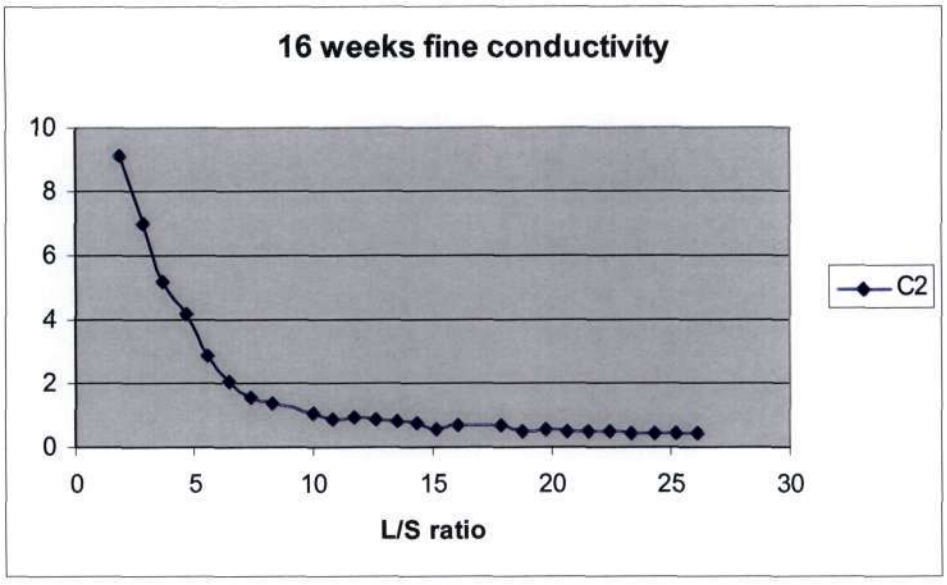

Figure 5.16 Conductivity for 16 weeks pre treated waste fine

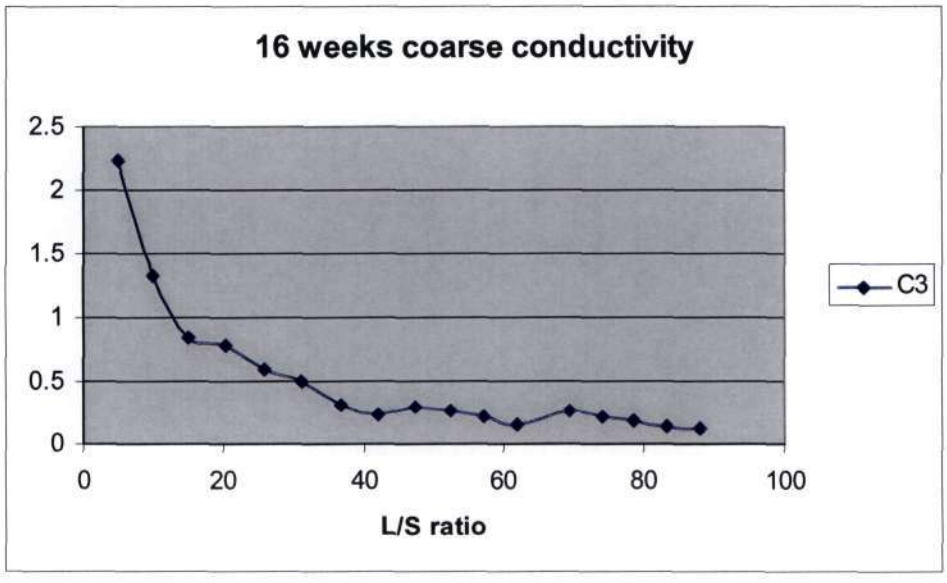

Figure 5.17 Conductivity for 16 weeks pre treated waste coarse

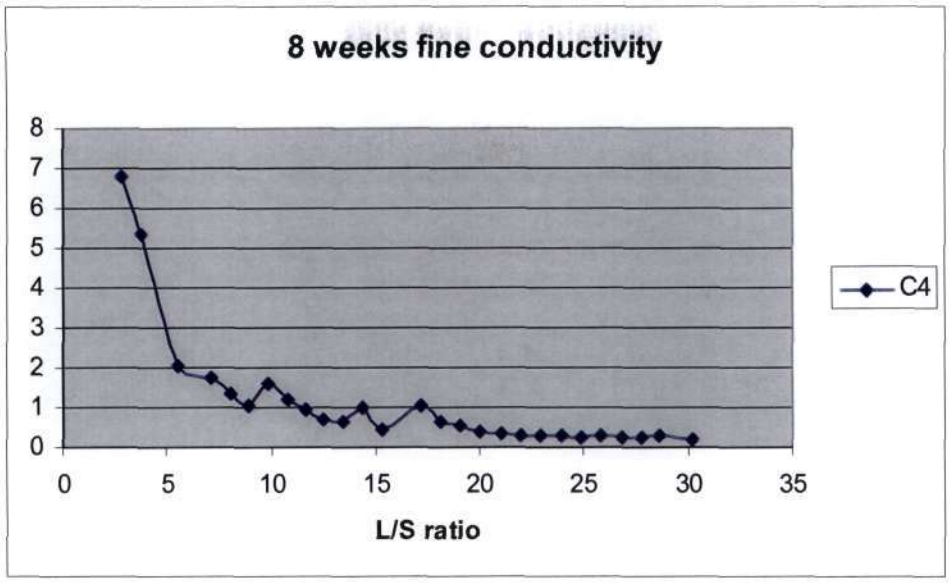

Figure 5.18 Conductivity for 8 weeks pre treated waste fine

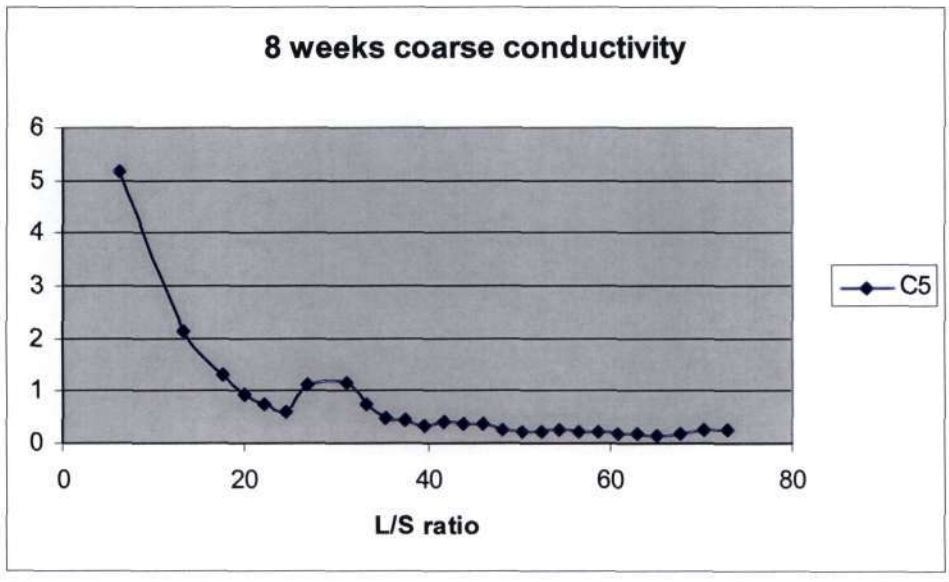

Figure 5.19 Conductivity for 8 weeks pre treated waste coarse

An evident decrease in the conductivity values is showed for Column 2; in the first 8 weeks conductivity starts from 9.13 mS/cm and decreases to 1.40 mS/cm asymptotically. The bacterial performance due the change from aerobic to anaerobic condition and the total solids leaching out can explain the conductivity decrease especially during the first period. The conductivity values for Column 3 present a peak of 2.24 mS/cm and then decrease slightly. The conductivity values of Columns 4 and 5

displays a similar asymptotically trend as in Column 2. The conductivity values of Column 1 after twenty weeks of testing seems in constant decrease from an initial value of 1.25 mS/cm due to the intense wash-out.

5.5.3 Solids

Figures 5.20 to 5.24 show the evolution with the L/S ratio of the solids in the five columns.

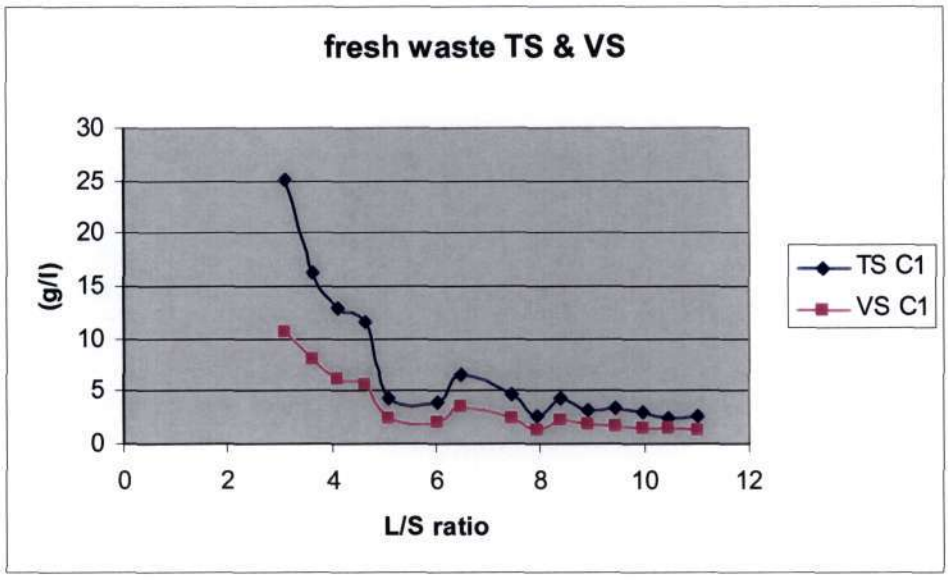

Figure 5.20 TS and VS for fresh waste

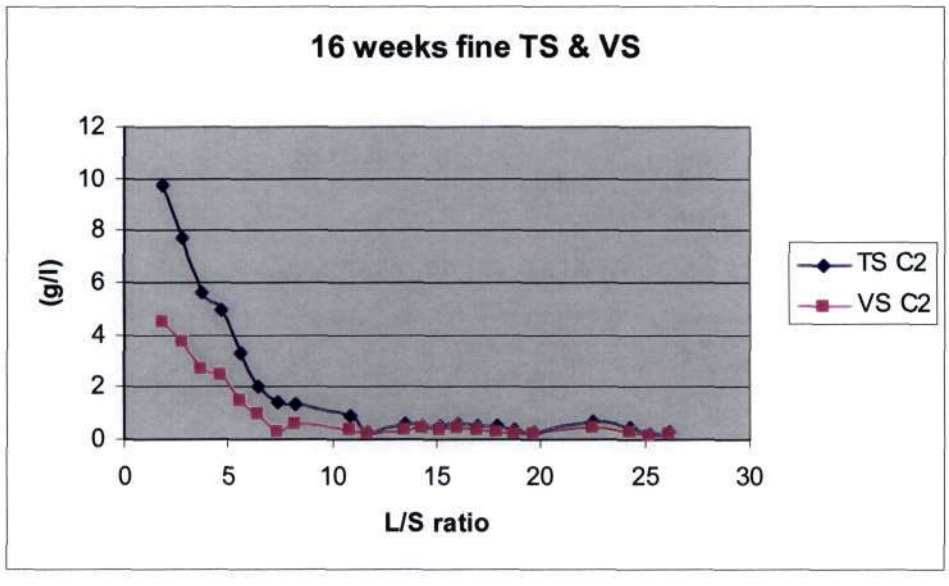

Figure 5.21 TS and VS for 16 weeks pre treated waste fine

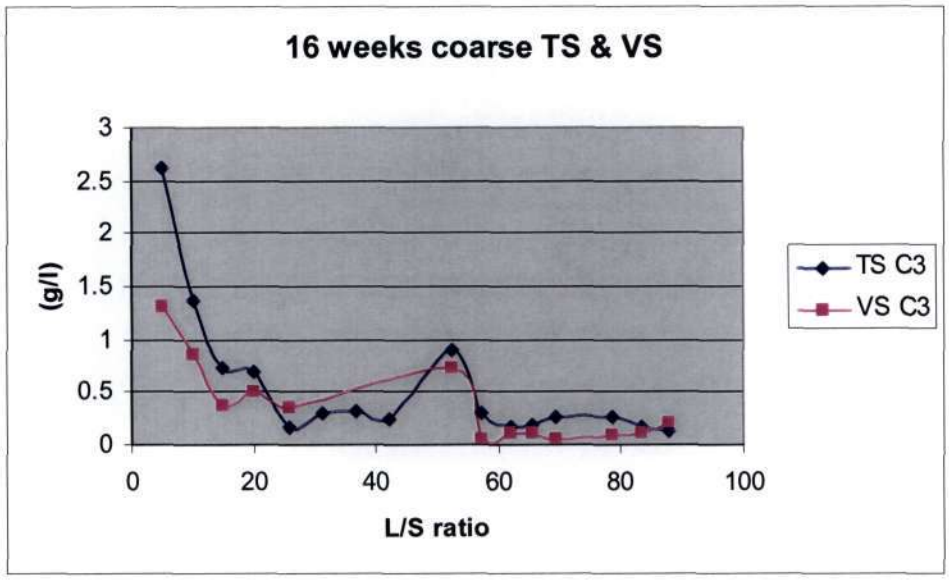

Figure 5.22 TS and VS for 16 weeks pre treated waste coarse

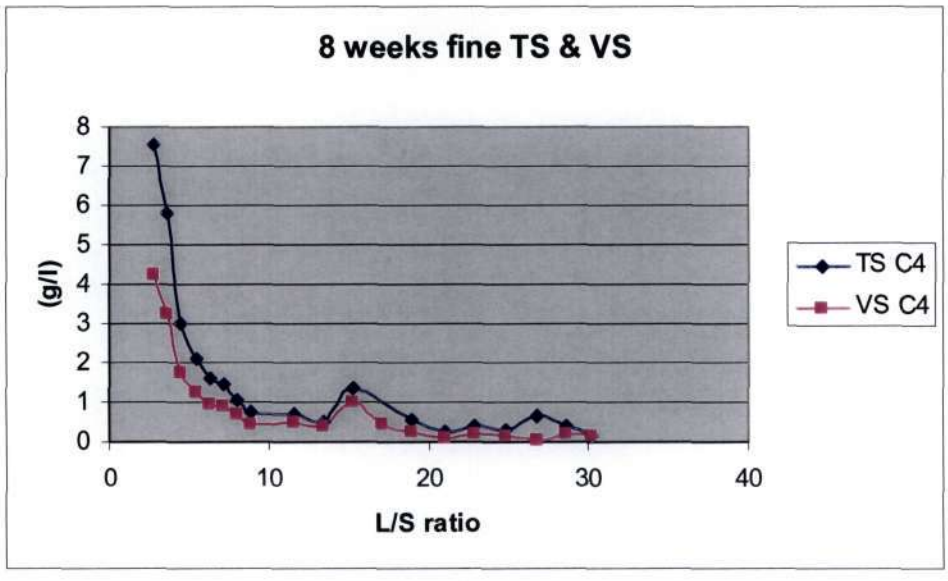

Figure 5.23 TS and VS for 8 weeks pre treated waste fine

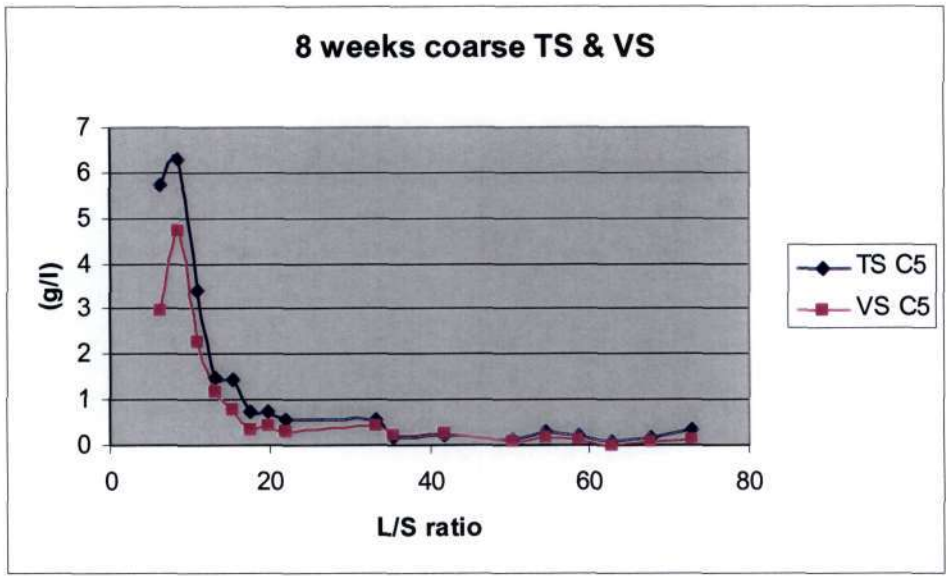

Figure 5.24 TS and VS for 8 weeks pre treated waste coarse

Initial high concentrations of TS and VS in each column decrease due to the biodegradation and the physical removal of solids by the action of water percolating through the waste body.

The trend is as expected since a heavy leaching rate was applied.

It is interesting to note that the treatment affects the amount of total solids; in fact there is an approximate reduction from 25 g/l in the fresh waste to 12.5 g/l in the 16 weeks global to 15 g/l in the 8 weeks global (see Appendix).

5.5.4 Chemical Oxygen Demand (COD)

Figures 5.25, 5.26, 5.27, 5.28 and 5.29 show the evolution of the COD concentrations for the columns.

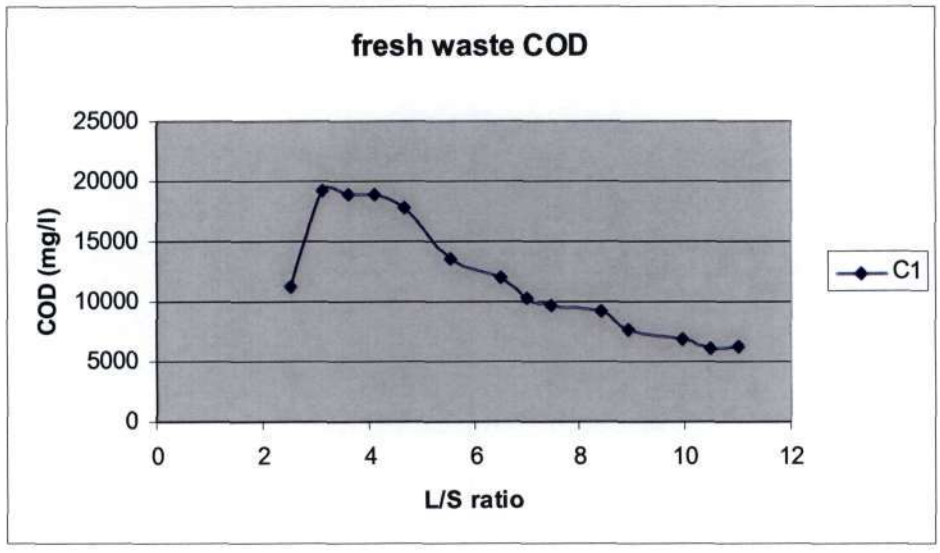

Figure 5.25 COD concentration for fresh waste

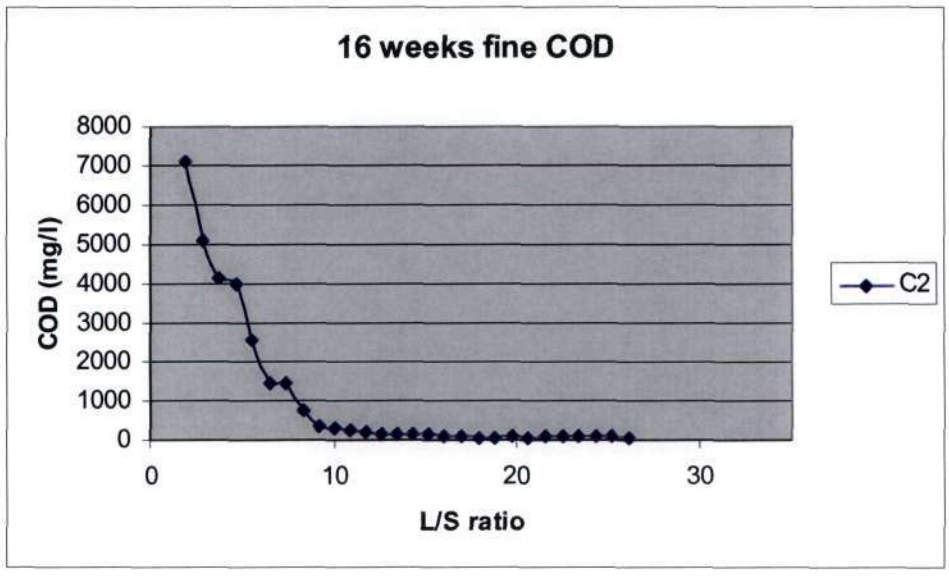

Figure 5.26 COD concentration for 16 weeks pre treated waste fine

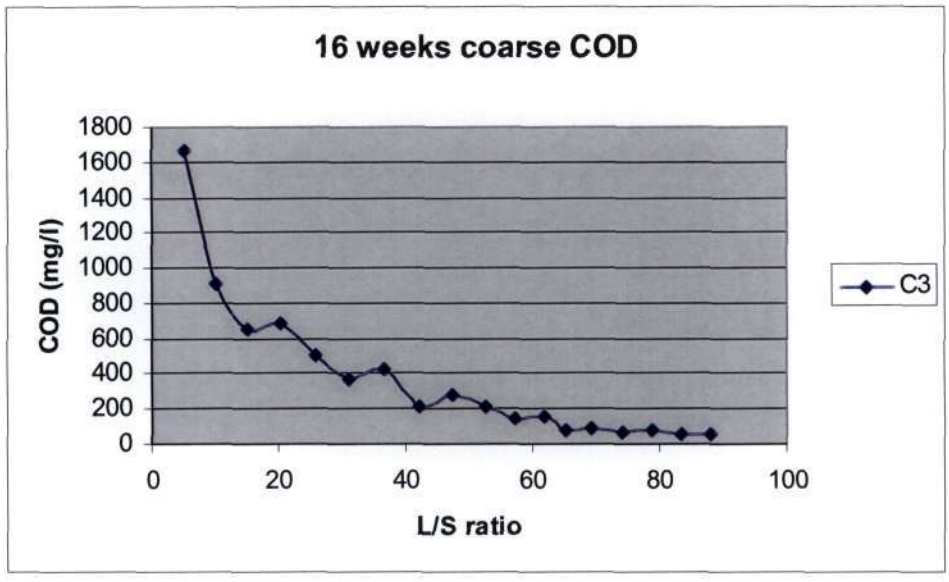

Figure 5.27 COD concentration for 16 weeks pre treated waste coarse

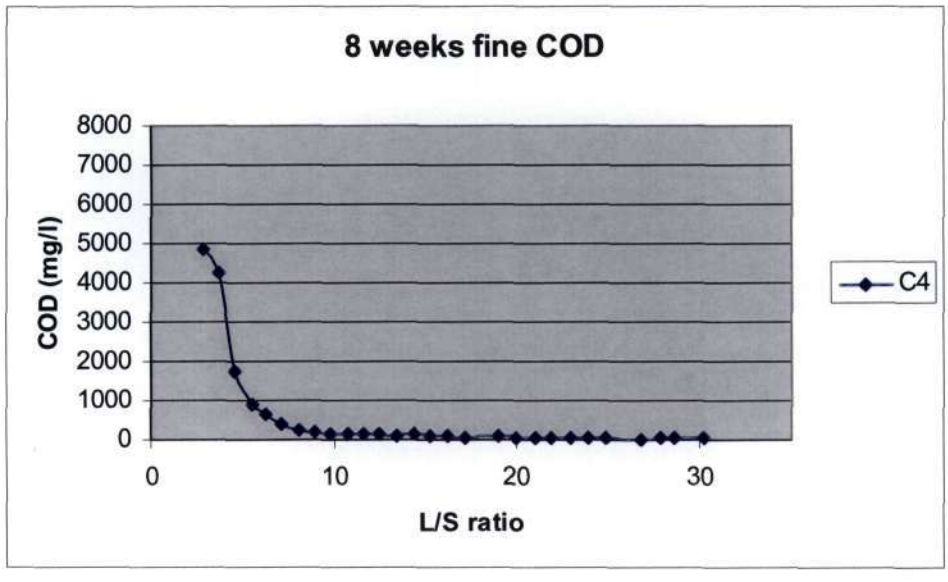

Figure 5.28 COD concentration for 8 weeks pre treated waste fine

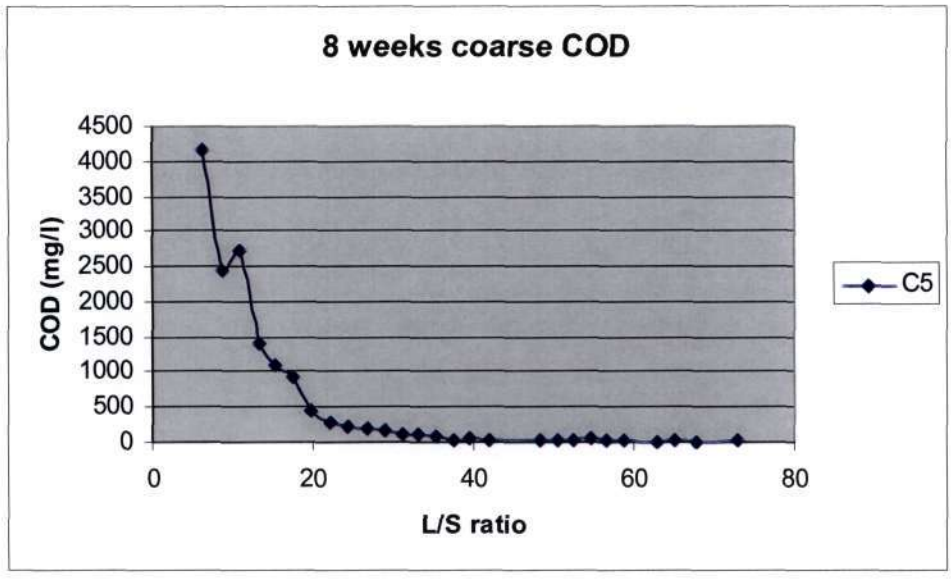

Figure 5.29 COD concentration for 8 weeks pre treated waste coarse

After this period and onwards the production of methane gas is noted in Columns 2, 4 and 5 because the facultative anaerobes begin to establish themselves and semi anaerobic conditions can start, while for Column 3 this process is seen in a latter stage. The reduced concentration of COD during these weeks is due to the onset of methanogenic phase and the progression of the leaching process at higher L/S ratios.

Also the rate of the reduction of the COD concentration may be due to the nature of the organic material within the columns; some of this material could be of a slowly or non biodegradable nature. Fresh waste COD shows that the column 1 is still in acetogenic/early methanogenic phase characterized by high COD and confirmed by pH and CH_4 trends. The 16 weeks and 8 weeks fine material displays a similar trend; where by the bulk of the reduction is obtained at an L/S ratio ranging between 5-10:1. It is interesting to note that the 16 weeks fine show a higher COD than 8 weeks fine to suggest that the two degree of pre treatment are comparable. There is an inverse trend in the coarse suggesting that the readily degradable COD in the fine fraction still present in the coarse is not removed quickly. The reduction of the amount of COD related to total amount of dry mass in the waste matrix is showed in Figures 5.30, 5.31 and 5.32.

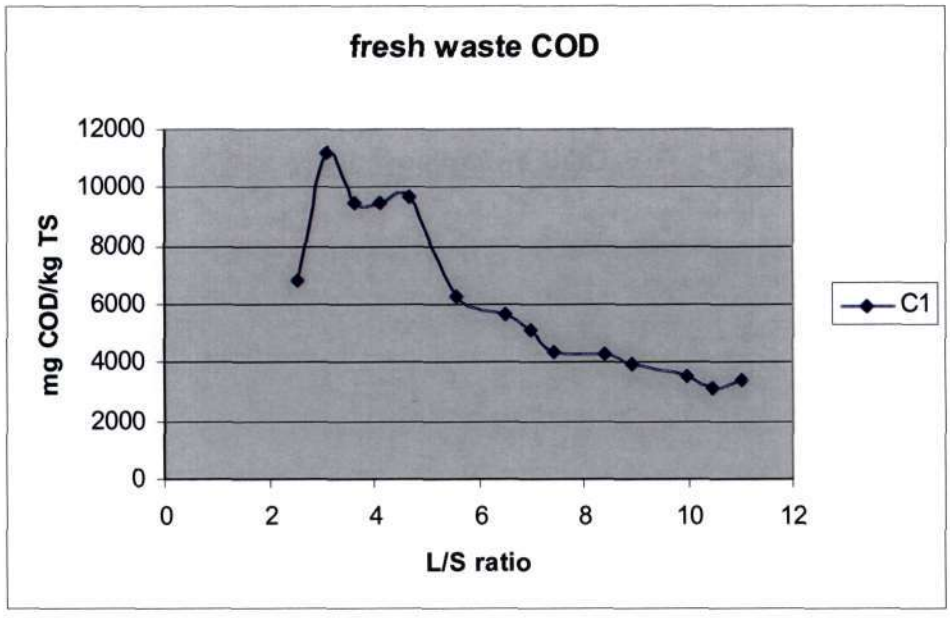

Figure 5.30 COD removed from fresh waste

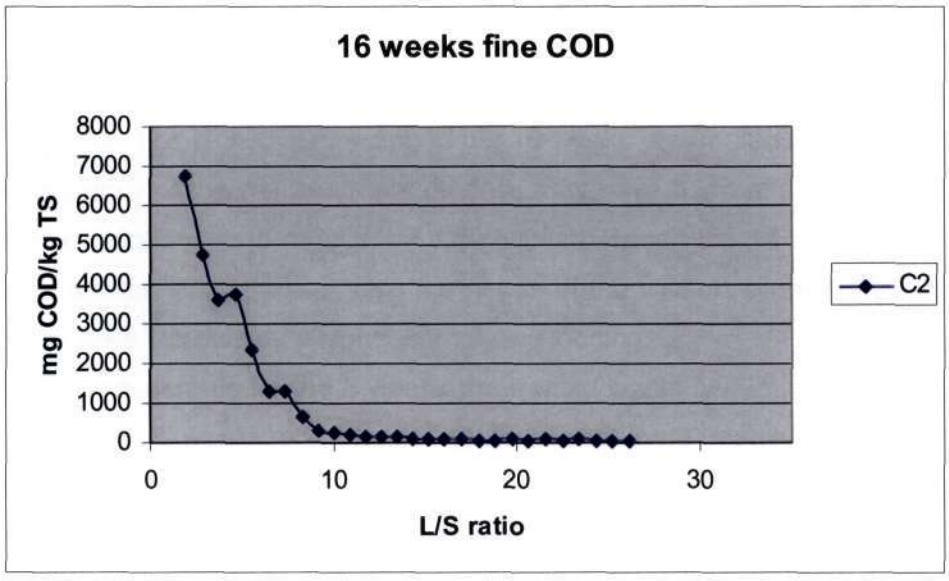

Figure 5.31 COD removed from 16 weeks pre treated waste fine

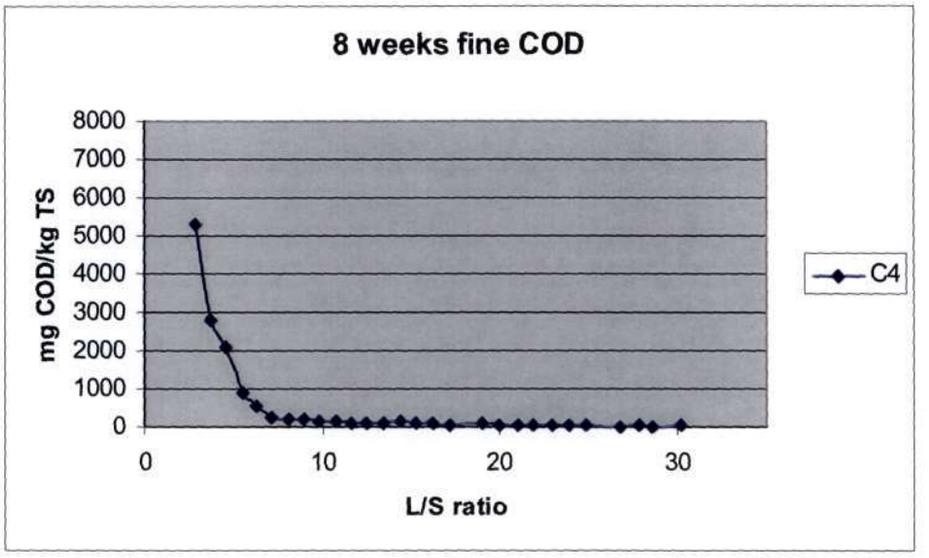

Figure 5.32 COD removed from 8 weeks pre treated waste fine

The majority of the reduction in COD is achieved at a leaching rate of 5-10:1 L/S for the treated material. The high COD loading in the 16 weeks pre treated waste fine suggests that the efficiency of the pre treatment process may have been affected by desiccation or excessive aeration, so to reduce the differences between the 16 weeks and 8 weeks pre treated wastes. Nonetheless, also the nature of the COD is slightly different so that the 8 weeks fines still display a higher cumulative loading.

The higher removal rates for the 8 weeks pre treated waste fine in the same L/S range, suggest that the 8 weeks pre treated waste fine is more readily biodegradable, as expected. The maximum COD removal is achieved between 5-15 L/S ranges; the following Figures 5.33, 5.34 and 5.35 shows the cumulative release for fresh waste and 16 and 8 weeks pre treated waste fine.

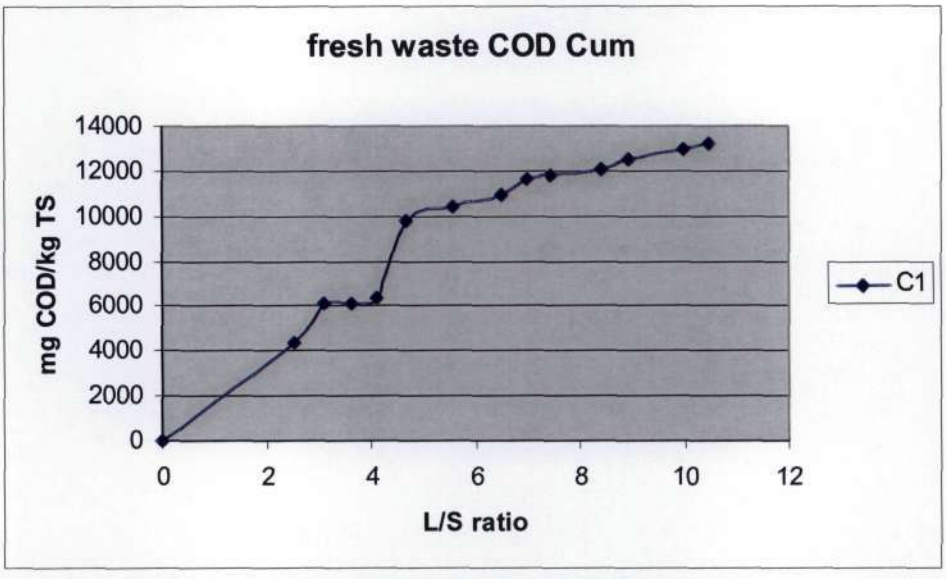

Figure 5.33 COD cumulative release from fresh waste

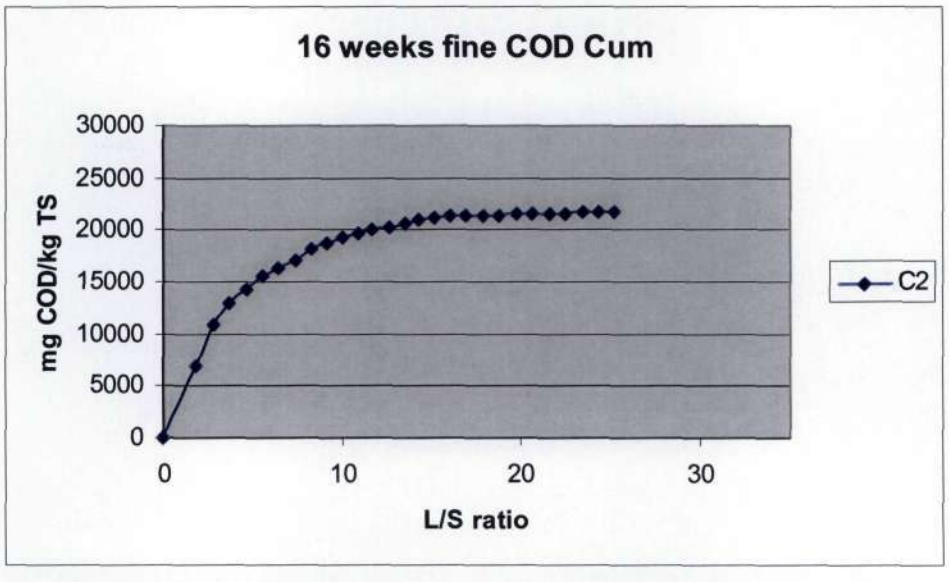

Figure 5.34 COD cumulative release from 16 weeks pre treated waste fine

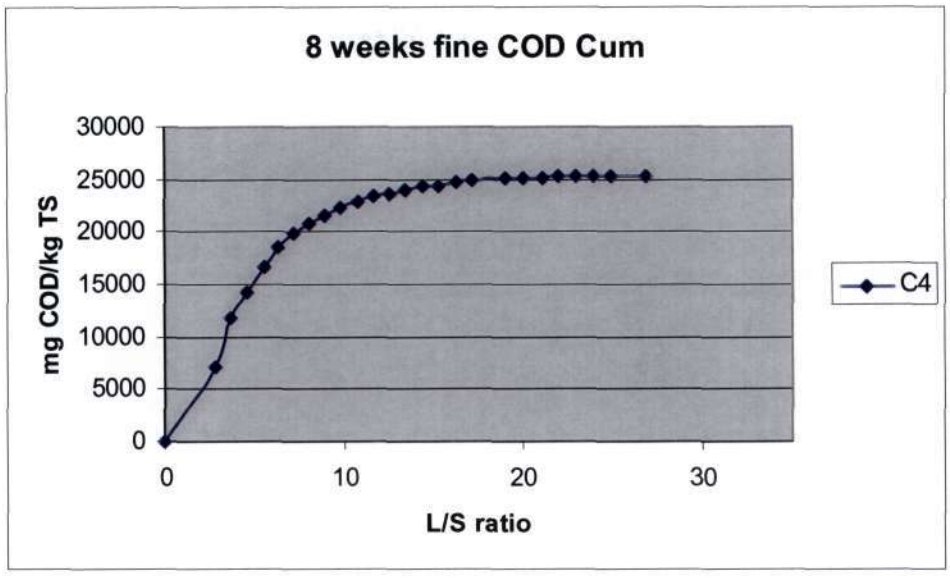

Figure 5.35 COD cumulative release from 8 weeks pre treated waste fine

5.5.5 Nitrogen Compounds

Figures 5.36, 5.37, 5.38, 5.39 and 5.40 show the concentrations of ammoniacal nitrogen within the columns.

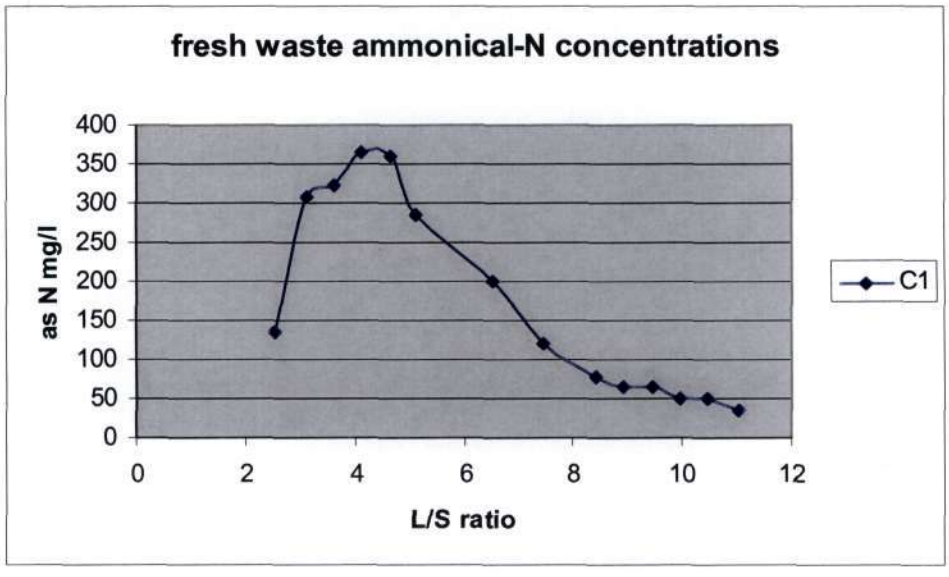

Figure 5.36 Ammoniacal - N concentrations from fresh waste

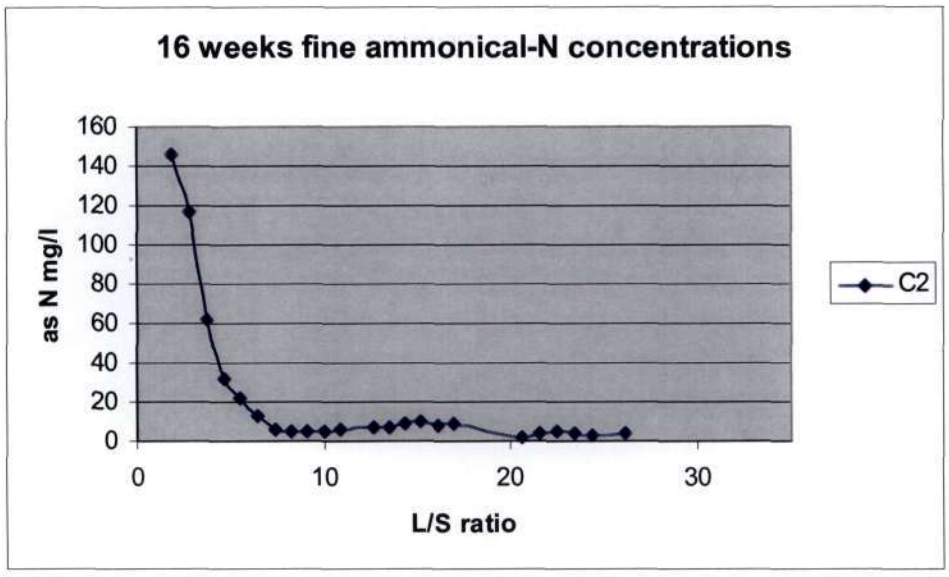

Figure 5.37 Ammoniacal - N concentrations from 16 weeks pre treated waste fine

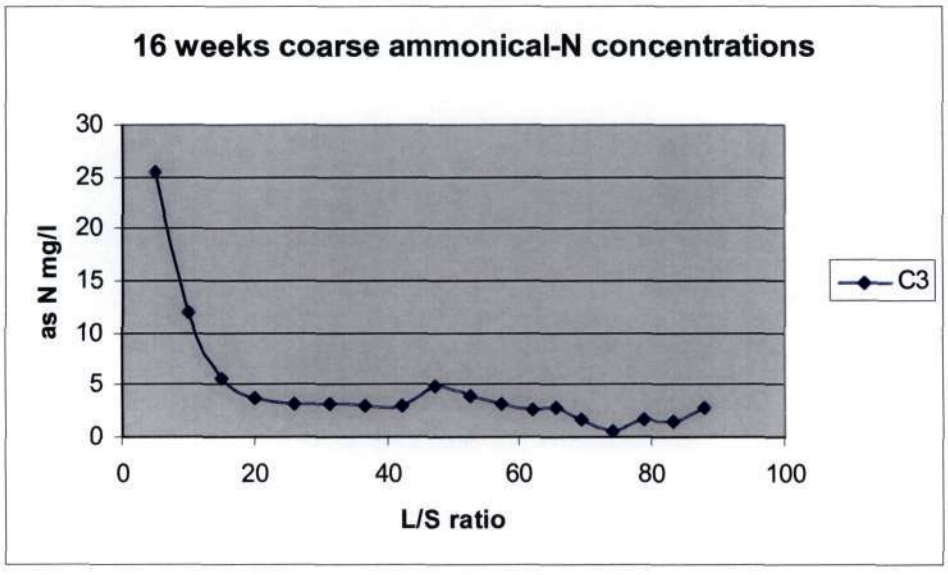

Figure 5.38 Ammoniacal - N concentrations from 16 weeks pre treated waste coarse

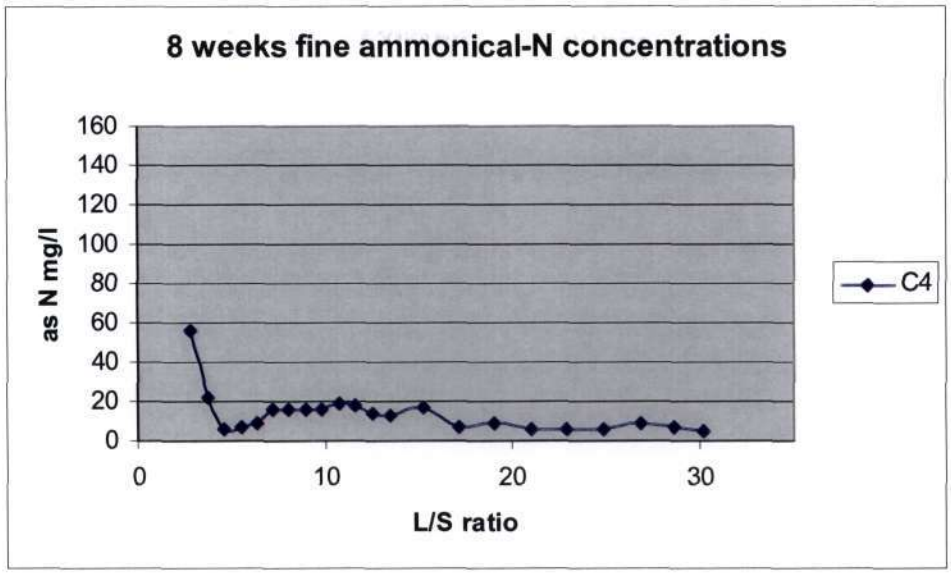

Figure 5.39 Ammoniacal - N concentrations from 8 weeks pre treated waste fine

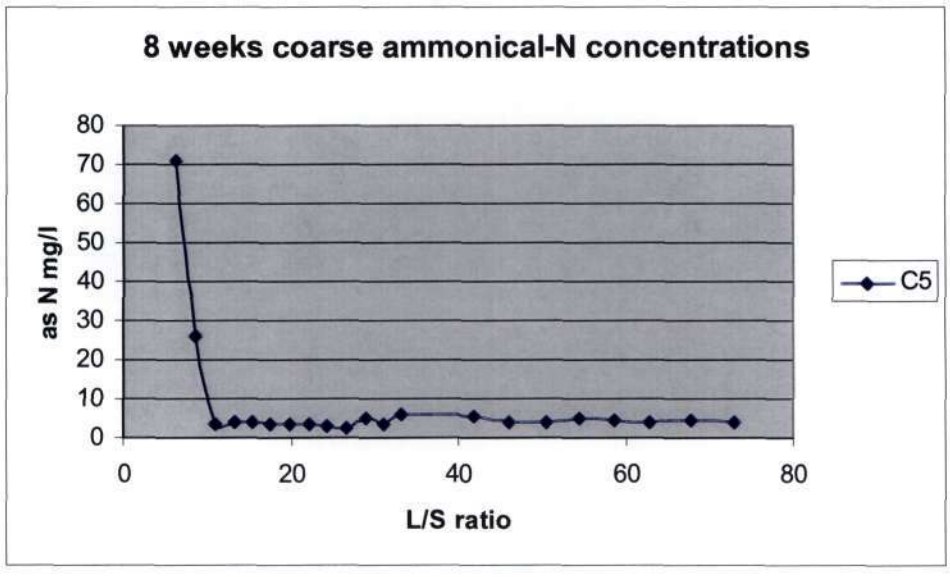

Figure 5.40 Ammoniacal - N concentrations from 8 weeks pre treated waste coarse

In fully anaerobic conditions ammoniacal-N concentrations should increase over time during acidogenic and early methanogenic phases to a constant value that proceeds for the entire methanogenic stage. However the columns are operated in semi anaerobic conditions due to the presence of oxygen and for this reason the concentrations of ammoniacal-N decrease in the columns, together with the high leaching rates.

The presence of nitrates is also an indication that fully anaerobic conditions were not prevalent as nitrification of ammonia compounds did occur.

In every column the nitrates trend is not always stable; this could be due to the fluctuations of oxygen levels within the columns caused by the weekly extracting of leachate which could affect the anaerobic condition within the columns.

High NH_3 values are evident in the fresh waste which is still entering in the early methanogenic phase; again a L/S ratio between 5-10:1 is required to reduce the concentration within the discharge limits. The comparison between the 16 weeks and 8 weeks pre treated wastes coarse show that the degradable material still retained in the matrix of the waste displays a readily degradable nature already noticed in COD. Pre treatment has helped to reduce the typical fresh waste built up ammonia but is not enough to achieve full reduction. The reduction of the amount of N concentrations related to total amount of dry mass in the waste matrix is shown in Figures 5.41, 5.42 and 5.43.

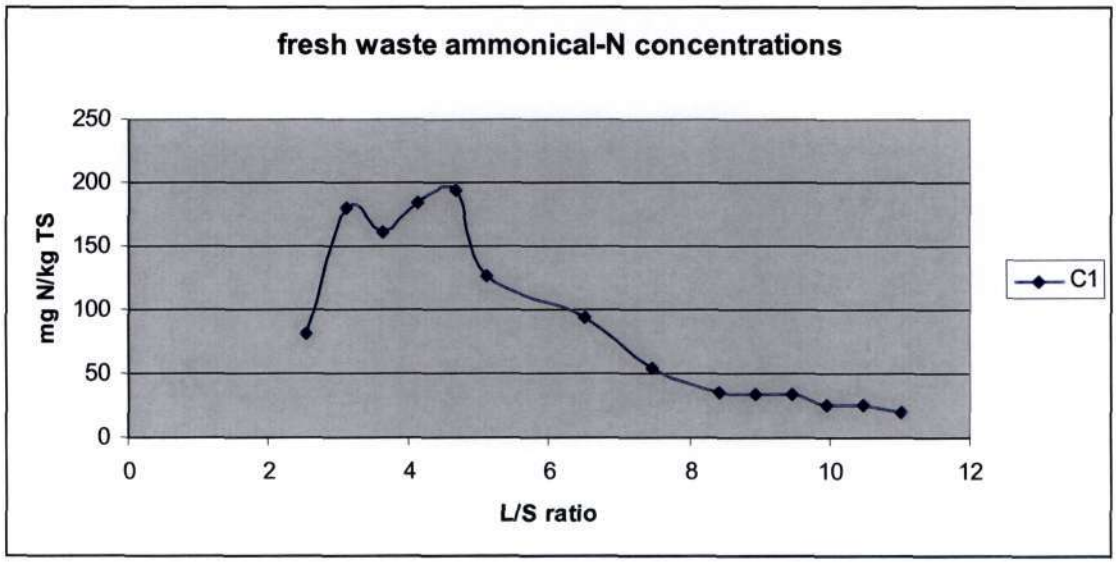

Figure 5.41 N concentations removed from fresh waste

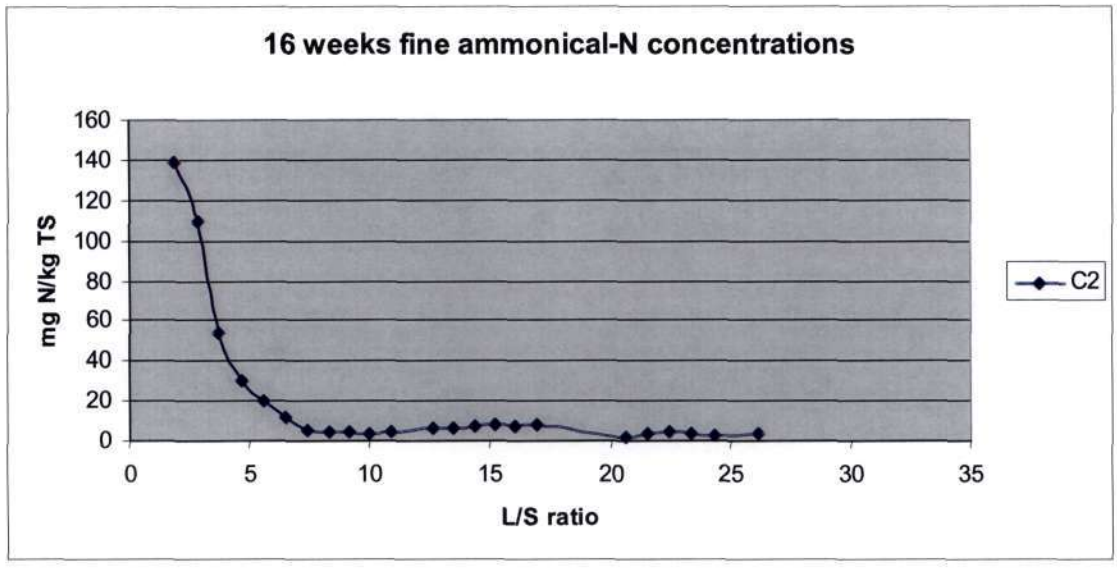

Figure 5.42 N concentrations removed from 16 weeks pre treated waste fine

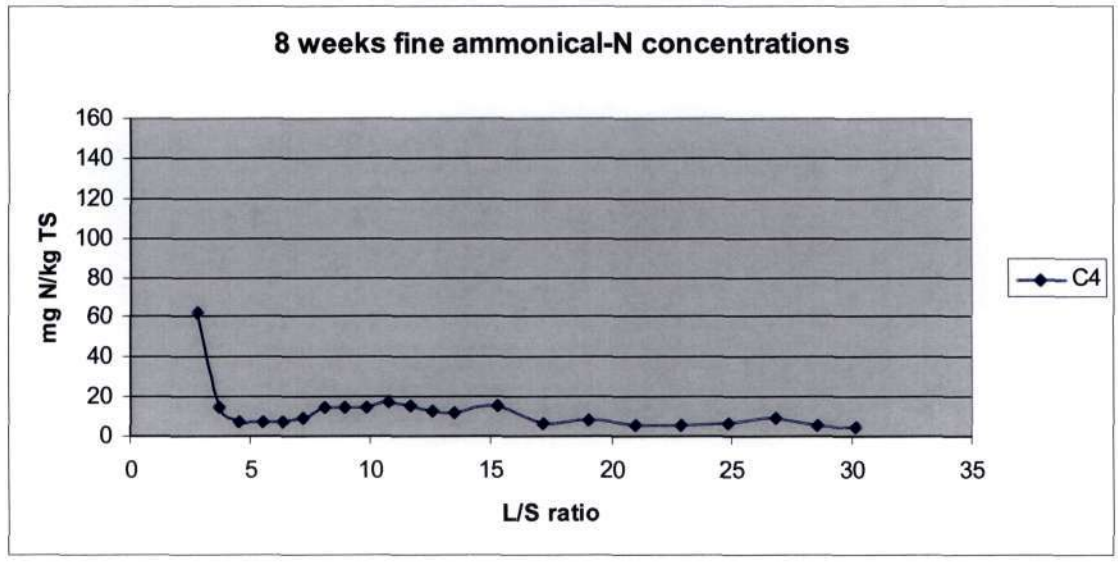

Figure 5.43 N concentrations removed from 8 weeks pre treated waste fine

The 8 weeks treatment is as efficient (if not more efficient) than the 16 weeks. It is interesting to notice that the 5-15:1 L/S ratio range is not efficient in removing the bulk of the ammonia loading. The 8 weeks pre treated waste fine still displays background concentrations which is above the discharge limits, suggesting that NH3 should be considered as heavily refractory to leaching campaigns. Figures 5.44, 5.45 and 5.46 show the cumulative release for fresh waste and 16 and 8 weeks pre treated waste fine;

the nitrates cumulative release for the same materials are reported in Figures 5.47, 5.48 and 5.49.

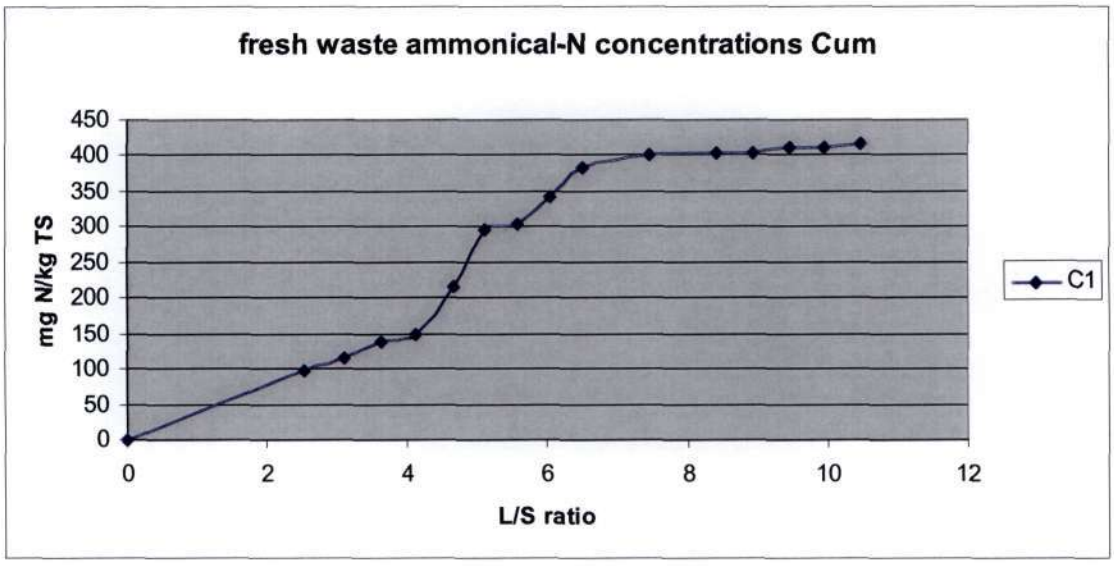

Figure 5.44 N cumulative release from fresh waste

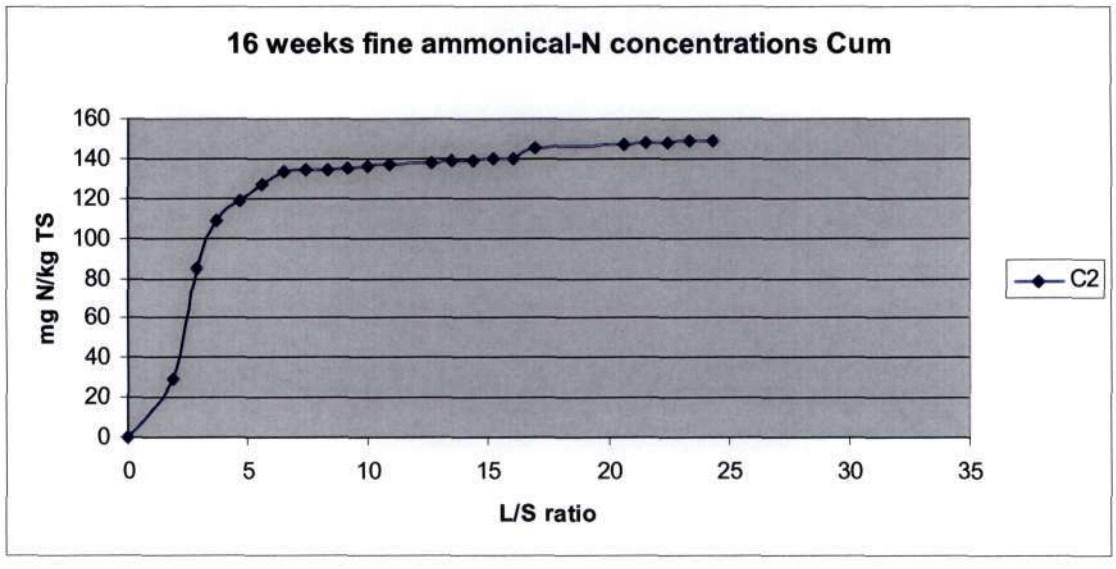

Figure 5.45 N cumulative release from 16 weeks pre treated waste fine

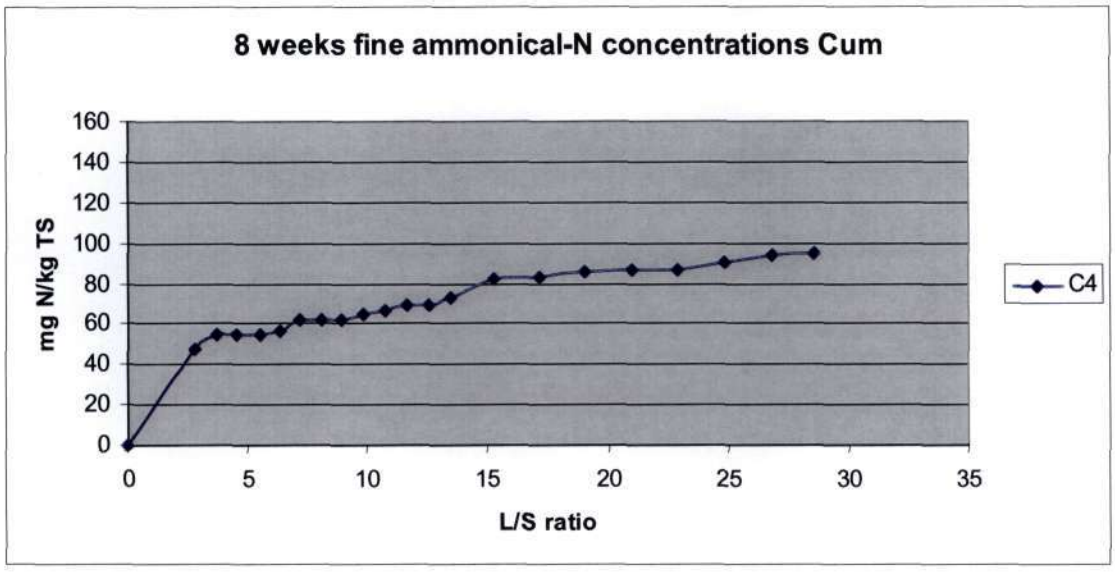

Figure 5.46 N cumulative release from 8 weeks pre treated waste fine

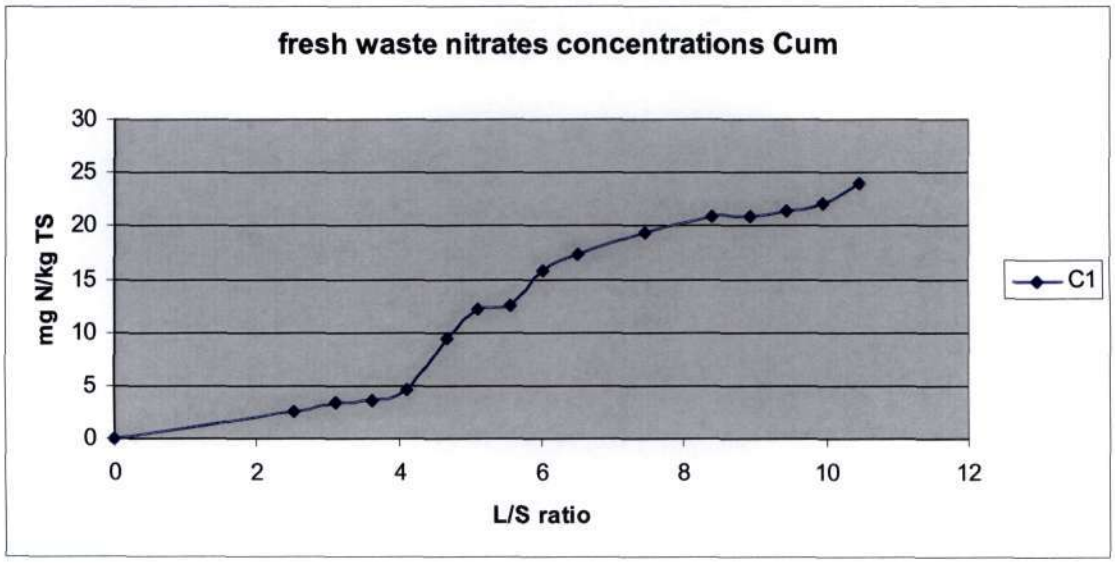

Figure 5.47 Nitrates cumulative release from fresh waste

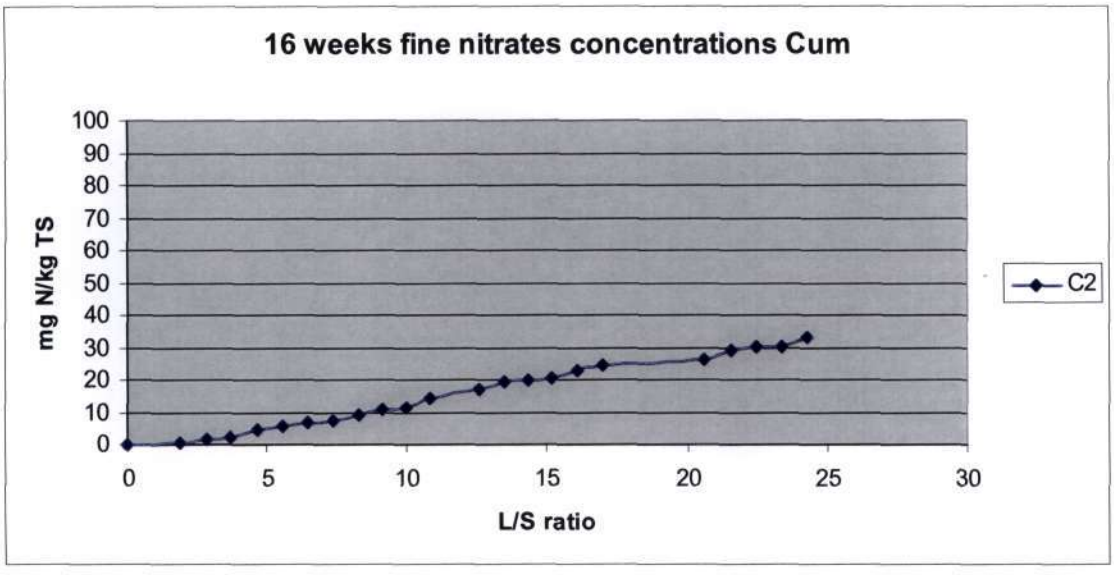

Figure 5.48 Nitrates cumulative release from 16 weeks pre treated waste fine

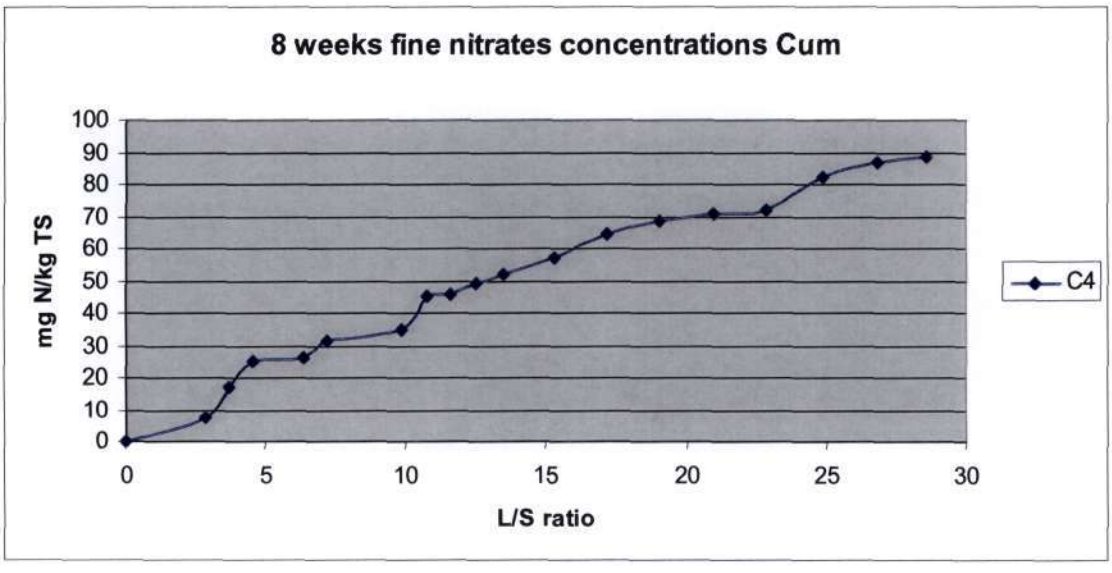

Figure 5.49 Nitrates cumulative release from 8 weeks pre treated waste fine

5.8 SUMMARY OF RESULTS

The columns are being studied to compare emissions from 16 week pre-treated waste, 8 weeks pre-treated waste and fresh waste. The results presented in Table 5.3 below are the comparisons between initial and final results obtained from the leachate analysis.

Table 5.3 Summary of Columns results

COLUMN 1 (fresh waste)			
Parameter	Initial	Final	% reduction
L/S ratio	2.54	11.03	
pH	4.53	4.80	
TS (g/l)	25.20	2.58	89.7
VS (g/l)	10.70	1.31	87.8
COD (mg/l)	11320.71	6232.32	44.9
NH_3 (mg/l)	136.22	36.12	73.5
NOx (mg/l)	16.24	1.96	87.9
COLUMN 2 (16 weeks pretreated waste fine)			
Parameter	Initial	Final	% reduction
L/S ratio	1.90	26.15	
pH	6.54	6.43	
TS (g/l)	9.78	0.29	97.1
VS (g/l)	4.52	0.26	94.3
COD (mg/l)	7080.75	70.55	99.0
NH_3 (mg/l)	146.00	3.52	97.6
NOx (mg/l)	6.00	1.72	71.4
COLUMN 3 (16 weeks pretreated waste coarse)			
Parameter	Initial	Final	% reduction
L/S ratio	5.13	87.89	
pH	6.77	5.94	
TS (g/l)	2.63	0.13	95.2
VS (g/l)	1.32	0.21	84.4
COD (mg/l)	1662.69	57.35	96.6
NH_3 (mg/l)	25.50	2.89	88.7
NOx (mg/l)	2.83	2.41	15.0
COLUMN 4 (8 weeks pretreated waste fine)			
Parameter	Initial	Final	% reduction
L/S ratio	2.83	30.18	
pH	6.12	6.56	
TS (g/l)	7.57	0.17	97.7
VS (g/l)	4.24	0.13	96.9
COD (mg/l)	4831.00	44.56	99.1
NH_3 (mg/l)	56.30	5.46	90.3
NOx (mg/l)	8.87	9.52	
COLUMN 5 (8 weeks pretreated waste coarse)			
Parameter	Initial	Final	% reduction
L/S ratio	6.30	72.88	
pH	6.24	5.84	
TS (g/l)	5.75	0.33	94.3
VS (g/l)	2.98	0.13	95.8
COD (mg/l)	4154.33	29.71	99.3
NH_3 (mg/l)	70.90	3.78	94.7
NOx (mg/l)	9.12	10.64	

Chapter 6 : CONCLUSIONS AND RECOMMENDATIONS

The key question that this investigation aimed to answer is related to the concept of sustainable landfill and the growing need to reduce the long term polluting potentials associated with the disposal of waste. More precisely, *is it possible to move from the "concentrate and contain" concept towards a more sustainable management of waste that incorporates accelerated stabilization of the organic fractions and creation of a more efficient flushing bioreactor?*

In order to answer this question, shared by the international scientific community, a detailed literature research was conducted to define the major processes responsible for the formation of liquid and gaseous emissions from modern landfills and to investigate the available techniques currently employed to reduce the environmental impacts associated with waste disposal. The literature review revealed that stabilization of the waste organic fractions, responsible for the long term release of carbon and nitrogenous contaminants can be achieved by waste treatment prior to disposal. While the European Landfill Directives enforce waste treatment in all the member states prior to landfilling, South Africa (an so the rest of the continent) is still anchored to the obsolete concept of "entombing" where untreated waste is disposed in engineered landfills which, once covered, prevent the ingress of oxygen and moisture so to retard degradation to a time frame of centuries and to an aftercare period as long as 30 to 40 years. A pilot project was initiated in 2002 in collaboration with Durban Solid Waste to investigate the feasibility of introducing waste treatment in the waste management strategies of the City. A comparative study of various waste disposal techniques (Chapter 3) indicated mechanical biological pre-treatment in open windrows as a suitable option in relation to low costs, low energy efforts and potential for labour intensive operations. Several full-scale windrows were constructed at the Bisasar Road landfill site and monitored over a period of 8, 16 and 20 weeks. This research is part of this larger project and focused primarily on understanding the dynamics of the physical removal of contaminants through the simulation of leaching processes that may occur in landfills containing MBP waste and operated as flushing bioreactors. The literature revealed that anaerobic leaching columns can be employed to simulate, in controlled laboratory conditions, flushing events in landfills operated with high liquid to solid ratios. Five columns were set up to investigate, together with the above mentioned key question, the influence of grain

size on the efficiency of pre-treatment, the hypothesis that fine fractions in pretreated waste (regardless of the degree of pre-treatment) contain a higher organic content than the coarse slowly biodegradable fractions. The dynamics of contaminants degradation and release during leaching events of slightly and heavily pretreated waste (8 and 16 weeks) were also monitored. The originality in this study lies in the absolute lack of comparisons with other local case studies, so to make the results unique for the prevailing conditions experienced in Durban but also interesting for other developing and subtropical countries. The analysis of the composition of the untreated waste used for the MBP treatment pilot shows that the waste stream of untreated waste entering Bisasar Rd landfill displays first world characteristics with 31% plastics, 22% putrescibles (fines) and 25% slowly degradable paper materials. This must be considered in analyzing the findings of the waste treatment trials (derived by the characterization of the input material to the columns) and the dynamics of the leaching/flushing simulations. The waste characterization campaign confirmed the initial hypothesis that fine fractions contain a higher organic content than the coarse material (evident from the composition of the pretreated waste). More over, eluate tests and the leaching campaigns suggested that the nature of the putrescibles (fines) is also readily biodegradable within the first 8 weeks of treatment. The analysis of the cumulative COD release in the columns suggests that the efficiency of the pre-treatment may decrease over time and the treatment itself is highly affected by ambient conditions which may lead to early desiccation and overall inefficiency. In general (global sample), the slowly biodegradable nature of the input waste to the windrows may have also played an important role in limiting the efficiency of the pre-treatment. Small differences between the behaviours of 8 weeks and 16 weeks pretreated waste have already been noted in other research so to conclude that only 8 weeks of aerobic composting, in similar climatic conditions, are sufficient to achieve the required levels of stabilization (according to EU standards) and so reducing excessive energy efforts (in the form of machinery, water, space availability). The efficiency of aerobic pre-treatment seems to increase with smaller fractions to suggest that MBP should be coupled with an appropriate separated collection and reuse strategy of the non biodegradable coarse fractions. The column studies suggested that where the availability of capital costs and know-how to set up full scale composting operations may be limited, as in other developing countries, but the availability of land is not an issue as well as suitable climatic conditions (tropical and subtropical regions) a possible waste management strategy could incorporate

mechanical separation, recycling of coarse fractions, light pre-treatment, disposal of the treated waste in aerobic (or aerated) landfills operated as flushing bioreactors. A liquid to solid ratio in the range of 3-5 is sufficient to induce the majority of the pollution reduction. The high volumes of leachate generated may constitute a drawback of this strategy in terms of handling requirements, but they should not constitute a problem in terms of treatment requirements since the low contaminants contents still present after treatment. Finally, columns studies are suitable to simulate leaching events and allow for a good understanding of the dynamics of contaminant transport in high L/S ratio conditions. However, dis-homogeneity of the substrate tested and uncertainties in the efficiency of the pretreatment make the laboratory scale application of this method not suitable for direct simulation of landfill processes. If the aim is to study the long term emissions from treated waste in landfill conditions, a larger scale reactor, operated at field capacity with varying influent flow rates should be employed. In conclusion, the efficiency of a flushing bioreactor landfill of treated waste is directly dependant, not on the operational mode adopted, but on the efficiency of the pretreatment and the nature of the disposed refuse.

REFERENCES

ASTM, Clesceri et al, (1989) American Standard Methods for the Examination of Water and Waste Water.(20th edn.) American Water Works Association (AWWA).

Baum B., Parker C.H. (1973), Solid Waste Disposal, Volume 1. Michigan: Ann Arbor Science Publishers.

Bone B.D., Knox K., Picken A. and Robinson H.D. (2003), The Effect of Mechanical and Biological Pretreatment on Landfill Leachate Quality. Proceedings SARDINIA 2003, 9th International Landfill Symposium, Environmental Sanitary Engineering Centre Cagliari, Italy, 2003

Bowers A. (2002), Masters Thesis: Characterization and Management of Landfill Emissions Under a Subtropical Climate Using Full-Scale Landfill Cells, Civil Engineering Programme, University of Natal, Durban, South Africa.

Buivid M.G. (1980), Laboratory Simulation of Fuel Gas Production Enhancement from Municipal Solid Waste Landfills, Dynatech R & D Co., Cambrigde, MA, USA

Christensen T.H. and Kjeldsen P. (1989), Basic Biotechemical Processes in Landfills. Sanitary Landfill: Process, Technology and Environmental Impact.

Christensen T.H. and Kjeldsen P. (1995), Landfill Emissions and Environmental Impact: An Introduction. Sardinia 95, 5th International Landfill Symposium, Conference Proceedings, Cagliari Italy.

Christensen T. H., Kjeldsen P. and Lindhardt B. (1996), Gas-Generating Processes in Landfilling of Waste: Biogas; E & FN Spon, London.

Cooper D. & Reinhart D. (1992), Landfill Gas Emissions, Civil and Environmental Engineering Department University of Central Florida, Orlando, Florida.

Cossu R., Andreottola G. and Muntoni A. (1996). Modelling landfill gas production, Landfilling of waste: biogas.

DWAF (1998), Minimum Requirements for Waste Disposal by Landfills. Waste Management Series, 2nd ed. Department of Water Affairs and Forestry, South Africa

Enhrig H.J. (1984). Laboratory scale tests for anaerobic degradation of municipal solid waste. Proceedings from the International Solid Wastes and Public Cleansing Association Congress, Philadelphia, 15 – 20 September, ISWA.

EPA (1995), Decision Maker's Guide to Solid Waste Management, Volume 2: US Environmental Protection Agency, USA.

Farquar G. J. and Rovers F.A. (1973), Gas Production during Refuse Decomposition.

Fourie A.B. and Morris J.W.F. (2002), Monitoring Leachate and Biogas Emissions from Existing Experimental Field Cells. Report to the Water Research Commission No. 995/1/02.

Gray K.R., Sherman K. and Biddlestone A.J. (1971), A Review of Composting Part 1 Process. Biochem. 6(6): 32-36. 41

Griffith M.R. (2005), An Investigation into the Mechanical Biological Pretreatment of Waste and its Effect on Landfill Emissions in South Africa. Master of Science in Engineering, Dissertation. University of Natal, Durban, South Africa.

Gurijala K.R. and Suflita J.M.(1993) Environmental Factors Influencing Methanogenesis from Refuse in Landfill Samples. Environmental Science and Technology. 27 (1993): 1176-1181.

Ham R. K. (1979), "Predicting Gas Generation from Landfills," Waste Age. November, 1979.

Ham R. K. (1988), Landfill Gas, Leachate, and Related Problems. Symposium: Institute of Waste Management of Southern Africa Biennial Congress, Durban, South Africa

Haug R.T (1993) The Pratical Handbook of Compost Engineering. Lewis Publishers.

Heerenklage, J., Stegmann, R. (1995), Overview on Mechanical-Biological Pretreatment of Residual MSW. Sardinia 95, 5th International Landfill Symposium, Conference Proceedings, Cagliari, Italy.

Johnson, L.D. (1981), Inhibition of anaerobic digestion by organic priority pollutants. PhD Thesis, Iowa State University, Ames, IA.

Knox K. (2000), Leachate Production: Prediction and Control, MSc Contaminated Land Management Landfill Module, Nottingham University, U.K.

Krogmann U. (1995), Anaerobic digestion or Composting for Waste Pretreatment. Proceedings SARDINIA 95, 5th International Landfill Symposium, Cagliari, Italy 1995.

Kuhle-Weidemeir M. and Doesens H. (2003), Landfilling and Properties of MBP Waste SARDINIA 2003 9th International Landfill Symposium, Conference Proceeding, Cagliari, Italy, 2003

Lamborn J. (1999), Modelling Landfill Gas Generation. Swinburne University of Technology, Victoria, Australia.

Leikam K. and Stegmann R. (1997), Mechanical-Biological Pretreatment of Residual Municipal Solid Waste and The Landfill Behaviour of Pretreated Waste. Sardinia 1997, 6th International Landfill Symposium, Conference Proceedings, Cagliari, Italy.

Lombard R. (2000), Monitoring of Gaseous Emissions, 1st International Training Seminar, University of Natal-Civil Engineering Programme, Durban, South Africa

Lombard R. (2005), Environmental Sanitary Engineering Notes, University of Natal, Durban, South Africa.

Maurice C. (1998). Landfill gas emission and landfill vegetation, Licentiate Thesis 1998:01, Luleå University of Technology, Luleå, S.

Mollekopf N., Brummack J., Paar S., and Vorster K. (2002), Use of the Dome AerationTechnology for Biochemical Stabilization of Waste Prior to Landfilling Dresden University of Technology. Wastecon 2002,Conference Proceedings, Durban, South Africa.

Munnich K., Mahler C.F. and Fricke K. (2005), Pilot Project of Mechanical-Biological Treatment of Waste in Brazil. Article in Press, Waste Management Series.

Muntoni A. and Trois C. (2005), Waste Stabilisation and Landfill Aftercare. The 2nd International Training Seminar on Control, Management and Treatment of Landfill Emissions, Durban, University of KwaZulu-Natal, Civil Engineering Programme, South Africa.

Novella P.H., Ballard R.H., Stow J.G., Ross W.R., Blight G.E. and Vorster K. (1999), Practical Application of Special Waste Co-Disposal with Municipal Refuse at the Coastal Park Landfill Bioreactor.

Paar S. (2000), Das Dombelüftungsverfahren – Ein Verfahren zur Belüftung offener Rottemieten unter Nutzung des thermischen Auftriebs. Dresden, Techn. Univ., (Translated into English)

Peavy H.S., Rowe D.R. and Tchobanoglous G. (1985), Environmental Engineering. McGraw-Hill Book Co., Singapore

Rees J.F. (1980), Optimisation of Methane Production and Refuse Decomposition in Landfills by Temperature Control. Journal of Chemical Technology and Biotechnology 30, 232 – 236.

Robinson H.D. (1989), Development of Methanogenic Conditions within Landfills. . Proceedings SARDINIA 89, 2nd International Landfill Symposium, Cagliari, Italy 1989.

Scheelhaase T. and Bidlingmaier W. (1997), Effects of Mechanical-Biological Pre-Treatment on Residual Waste and Landfilling. Sardinia 97, 6th International Landfill Symposium, Conference Proceedings, Cagliari, Italy.

Soyez K., Thran D., Volker D., Koller M. (1997), The German Federal Research Programme on Mechanical Biological Pre-treatment. SARDINIA 97, 6th International Landfill Symposium, Conference Proceedings, Cagliari, Italy, 1997

Soyez K. and Plickert S. (2002), Mechanical-Biological Treatment of Waste (MBP) – Integration into Waste Management Concepts. Wastecon 2002 Symposium, Conference Proceedings, Durban, South Africa.

Soyez K. and Plickert S. (2003), Material Flux Management of Waste by Mechanical Biological Pre-Treatment. SARDINIA 2003, 9th International Landfill Symposium, Conference Proceedings, Cagliari, Italy, 2003.

Stegmann R. and Spendlin H.H. (1985). Research activities on enhancement of biochemical processes in sanitary landfills. Paper presented at the Conference New Direction and Reaserch on Enhancement of Biochemical Processes in Sanitary Landfills, 23-28 June, University of British Columbia, Vancouver, Canada.

Stegmann R (2005) Mechanical Biological Pretreatment of Municipal Solid Waste. Conf. Proc. SARDINIA 2005, 10th Int. Landfill Symp. Santa Margherita di Pula, Cagliari, Italy, October 2005.

Stentiford E.I. (1996), Composting Control: Principles and Practice. In the science of composting, edited by De Bertoldi M., Sequi P., Lemmes B., Papi T. (1996), London: Chapman & Hall.

Trois C, Griffith M, Mollekopf N and Brummack J (2005) A Comparative Study Of Aerobic Waste Treatment: A Solution For Developing Countries. Conf. Proc. SARDINIA 2005, 10th Int. Landfill Symp. Santa Margherita di Pula, Cagliari, Italy, October 2005.

Trois, C., Marcello, A., Pretti, S, Trois, P, Rossi, G. (2006). The Environmental Risk Posed By Small Dumps Of Complex Arsenic, Antimony, Nickel And Cobalt Sulphides. Journal of Geochemical Exploration. Elsevier. In press.

Visser G.A, Bell S.E, Boswell J.E.S, Tladi B, (2002).Waste Management in South Africa: The Role of Government, Wastecon 2002. Conference Proceedings, Durban South Africa 2002.

Visvanathan C. (2004), Mechanical Biological Pre-treatment of Solid Waste Prior to Landfill. Environmental Engineering and Management Program Asian Institute of Technology. Thailand.

Williams P.T. (1998), Waste Treatment and Disposal. John Wiley and Sons, Chichester

Ziegler C. (1997), Nitrogen fixation and release from Biological Pretreated MSW SARDINIA 1997, 6th International Symposium, Conference Proceeding, Cagliari Italy 1997

APPENDIX

8.1 weekly extractions, ph, conductivity and gas analysis

8.1.1 Column 1 (Fresh Waste)

Date	Weeks	Ext	Add	pH	Conductivity	CH4	CO2	O2
23-May	1	2970	2970	4.53	1.251	0.4	80.1	0
31-May	2	2890	2890	5.22	1.04	0.5	91.4	0
6-Jun	3	2474	2474	5.52	0.928	0.3	85.8	0.2
13-Jun	4	2486	2486	5.42	0.742	0.04	90	0.2
20-Jun	5	2682	2682	5.35	0.699	0.4	66.2	0.1
27-Jun	6	2202	2202	5.06	0.623			
4-Jul	7	2278	2278	5.04	0.525	0.2	26	0.3
11-Jul	8	2280	2280	4.9	0.517	0.3	26.4	0.9
18-Jul	9							
25-Jul	10	2342	2342	5.05	0.443	0.3	21.7	0.6
2-Aug	11	2456	2456	5	0.368	1	19.6	1.3
8-Aug	12	2252	2252	5.14	0.269	2.9	16.9	0.7
15-Aug	13	2446	2446	5	0.261	5.7	16.6	0.5
22-Aug	14	2272	2272	4.78	0.249	7.1	14.6	0.1
27-Aug	15							
5-Sep	16	2564	2564	4.84	0.1877	6.7	10.4	0.2
12-Sep	17	2566	2566	4.64		18.9	23.3	0.4
19-Sep	18	2550	2550	4.37		10.4	15.1	0.1
26-Sep	19	2534	2534	4.82		12.7	16.7	0.3
3-Oct	20	2726	2726	4.8		16.7	20.4	0.3

8.1.2 Column 2 (16 weeks pre treated waste fine)

Date	Weeks	Ext	Add	pH	Conductivity	CH4	CO2	O2
13-Sep	1			6.54	9.13	0	2.8	15.9
21-Sep	2			6.51	7.03	0	9.6	6.3
27-Sep	3			6.15	5.19	0.8	12	3.6
4-Oct	4			6.25	4.18	3.7	12.2	3.1
11-Oct	5			6.24	2.88	28.3	22.5	0.5
19-Oct	6			6.34	2.07	48.4	34.2	0.6
25-Oct	7			6.32	1.586	51.5	34.4	1.4
1-Nov	8			6.25	1.395	50.6	30.2	0.7
9-Nov	9					47.6	18.3	
15-Nov	10			6.31	1.04	43.5	17.2	0.2
21-Nov	11			6.12	0.897	46.7	17.9	0.2
29-Nov	12			6.16	0.914	43.8	17.3	0.2
6-Dec	13			6.38	0.857	39.2	14.1	0.8
15-Dec	14				0.795	36.2	11.9	0.3
22-Dec	15			6.29	0.752	22.4	6.5	4.1
28-Dec	16			6.46	0.549	18.4	4.5	2.5
5-Jan	17			6.08	0.703	27	7	0.7
11-Jan	18					27.3	7.2	1
24-Jan	19			6.4	0.701	36.8	11.5	1.5
2-Feb	20			6.56	0.526	21.7	6.3	3.1
10-Feb	21			6.31	0.556	21.5	6.7	1.7
16-Feb	22	4826	4826	6	0.512	21.6	5.5	0.7
22-Feb	23	5008	5008	6.42	0.499	22.4	5.3	2.7
6-Mar	24	4906	4906	6.25	0.477	17.4	4.7	2.4
9-Mar	25	4856	4856	5.85	0.415	9.3	3	6.7
16-Mar	26	4873	4873	6.2	0.457	6.6	1.6	11.7
23-Mar	27	4930	4930	6.43	0.434	14.3	3.5	2.4
30-Mar	28			6.43	0.442	9.9	2.3	1.7

8.1.3 Column 3 (16 weeks pre treated waste coarse)

Date	Weeks	Ext	Add	pH	Conductivity	CH4	CO2	O2
13-Sep	1			6.77	2.24	0	2.5	14.9
21-Sep	2			6.54	1.33	0	3.4	13.8
27-Sep	3			6.35	0.848	0	4.1	13.3
4-Oct	4			6.18	0.789	0	3.1	14.8
11-Oct	5			6.04	0.59	0.1	2.1	16.7
19-Oct	6			5.81	0.5	0.2	4.1	13.2
25-Oct	7			5.88	0.32	0.4	1.7	17.3
1-Nov	8			5.78	0.228	0.3	7.7	8.5
9-Nov	9							
15-Nov	10			6.25	0.291	0.3	4.1	3.1
21-Nov	11							
29-Nov	12			5.85	0.258	4.8	4.5	0.4
6-Dec	13							
15-Dec	14			5.68	0.226	10.6	4.4	0.3
22-Dec	15							
28-Dec	16			6.04	0.15	2.6	3	13
5-Jan	17							
11-Jan	18					3.1	1.5	
24-Jan	19							
2-Feb	20			5.77	0.26	29.2	12.7	0.4
10-Feb	21					16.8	4.3	0.9
16-Feb	22	7582	7582	5.61	0.225	28.5	7.3	0.8
22-Feb	23					19.5	5.2	0.5
6-Mar	24	7558	7558	5.97	0.193	28.8	9.1	0.5
9-Mar	25							
16-Mar	26	7460	7460	5.7	0.1471	13.3	6.6	0.6
23-Mar	27					7.9	3.7	0.6
30-Mar	28			5.94	0.131	8.2	5	1

8.1.4 Column 4 (8 weeks pre treated waste fine)

Date	Weeks	Ext	Add	pH	Conductivity	CH4	CO2	O2
15-Dec	1			6.12	6.82	0.8	9.3	12.7
22-Dec	2			6.09	5.36	17.4	25.7	3.5
28-Dec	3					53.3	32.6	0.5
5-Jan	4			6.31	2.06	42	23.6	0.3
11-Jan	5					52.5	25.8	0.1
24-Jan	6			6.41	1.728	53.2	33.2	1
2-Feb	7			6.41	1.327	51.5	21.5	0.8
10-Feb	8			6.27	1.057	40.7	12	0.2
16-Feb	9	5648	5648	6.34	1.581	28.2	7.6	0.4
22-Feb	10	5494	5494	6.39	1.201	37.1	9	0.2
6-Mar	11	5392	5392	6.29	0.959	41.6	8.8	0.7
9-Mar	12	5570	5570	6.11	0.691	23.5	5	0.5
16-Mar	13	5764	5764	6.43	0.667	28.9	4.6	0.6
23-Mar	14	5580	5580	6.34	0.986	22.5	11.5	0.9
30-Mar	15			6.5	0.446	9.6	5	0.5
6-Apr	16	5934	5934	6.69	1.893	7.7	5.3	0.7
13-Apr	17	5670	5670	6.82	1.03	6.5	3.2	1.1
20-Apr	18	5702	5702	6.79	0.673	4	0.9	3.8
2-May	19	5858	5858	6.84	0.54	9.6	3.2	0.7
9-May	20	6002	6002	6.8	0.39	3.9	1.1	1.5
16-May	21	6222	6222	6.87	0.326	2.2	0.8	3.5
23-May	22	5772	5772	7.01	0.304	1.7	0.7	1.3
31-May	23	6042	6042	6.73	0.308			
6-Jun	24	6092	6092	7.02	0.277	2	0.7	0.9
13-Jun	25	6072	6072	6.77	0.269	1.7	0.3	1.3
20-Jun	26	5946	5946	6.83	0.291	1.7	0.5	1.6
27-Jun	27	6116	6116	6.92	0.262	2.7	0.7	0.7
4-Jul	28	6180	6180	6.76	0.253			
11-Jul	29	4838	4838	6.77	0.281	3.7	0.7	0.4
25-Jul	30	5124	5124					
2-Aug	31							
8-Aug	32	4694		6.56	0.201			

8.1.5 Column 5 (8 weeks pre treated waste coarse)

Date	Weeks	Ext	Add	pH	Conductivity	CH4	CO2	O2
15-Dec	1			6.24	5.16	0.1	11.8	1.8
22-Dec	2			6.04	7.92	2.8	21.2	2.7
28-Dec	3					12.3	16	0.4
5-Jan	4			6.05	2.13	30.9	20.9	0.2
11-Jan	5					38.5	19.1	0.2
24-Jan	6			6.18	1.312	55.8	30.4	0.8
2-Feb	7			6.13	0.928	52.7	24.1	0.5
10-Feb	8			5.84	0.742	43.8	16.8	0.2
16-Feb	9	6104	6104	6.11	0.588	47.1	15.4	0.7
22-Feb	10	6026	6026	6	1.122	50.1	18.6	0.2
6-Mar	11	5858	5858	5.96	2.35	42.6	18.6	0.2
9-Mar	12	5778	5778	5.89	1.152	33.7	13.7	0.6
16-Mar	13	5552	5552	6.05	0.753	45.3	13.6	0.6
23-Mar	14	5774	5774	6.26	0.479	32	14.6	0.6
30-Mar	15			6.17	0.441	34.5	9.6	0.4
6-Apr	16	5680	5680	6.11	0.347	33.5	15.5	0.4
13-Apr	17	5842	5842	6.2	0.413	41.4	11.1	1.5
20-Apr	18	5580	5580	6.1	0.361	30.8	10.4	0.9
2-May	19	5870	5870	6.2	0.36	25.9	10.8	1.2
9-May	20	5524	5524	6.22	0.27	18.7	6	0.3
16-May	21	5668	5668	5.94	0.24	16.4	5	0.3
23-May	22	5406	5406	6.3	0.24	16.9	5.2	0.2
31-May	23	5496	5496	6.37	0.264	12.5	3.6	0
6-Jun	24	5234	5234	6.09	0.233	7	3.1	0.9
13-Jun	25	5814	5814	6.16	0.219	9.5	3.6	2.6
20-Jun	26	5830	5830	6.14	0.203	7.7	3.2	1
27-Jun	27	5448	5448	6.28	0.1804	7.4	2.8	0.6
4-Jul	28	5612	5612	6.19	0.165			
11-Jul	29	6890	6890	6.2	0.18	12.3	2.5	0.2
25-Jul	30	6726	6726	6.12	0.255			
2-Aug	31							
8-Aug	32	6904		5.84	0.255			

Extraction and Addition of water expressed in ml

Conductivity expressed in mS/cm

CH_4, CO_2 and O_2 expressed in %volume

8.2 total solids and volatile solids

8.2.1 Column 1 (Fresh Waste)

Date	Weeks	TS	VS
23-May	1		
31-May	2	25.2	10.69733
6-Jun	3	16.38533	8.061333
13-Jun	4	12.93867	6.238667
20-Jun	5	11.636	5.646667
27-Jun	6	4.318667	2.416
4-Jul	7	13.20133	7.469333
11-Jul	8	3.984	2.056
18-Jul	9		
25-Jul	10	6.496	3.510667
2-Aug	11		
8-Aug	12	4.664	2.484
15-Aug	13	2.633333	1.288
22-Aug	14	4.282667	2.214667
27-Aug	15		
5-Sep	16	3.174667	1.794667
12-Sep	17	3.314667	1.653333
19-Sep	18	2.953333	1.570667
26-Sep	19	2.357333	1.478667
3-Oct	20	2.584	1.308

8.2.2 Column 2 (16 weeks pre treated waste fine)

Date	Weeks	TS	VS
13-Sep	1	9.782	4.5242
21-Sep	2	7.708	3.722
27-Sep	3	5.628	2.732
4-Oct	4	4.948	2.5
11-Oct	5	3.332	1.472
19-Oct	6	2.026	0.946
25-Oct	7	1.434	0.286
1-Nov	8	1.33	0.59
9-Nov	9		
15-Nov	10		
21-Nov	11	0.892	0.41
29-Nov	12	0.296	0.194
6-Dec	13		
15-Dec	14	0.614	0.364
22-Dec	15	0.536	0.424
28-Dec	16	0.494	0.402
5-Jan	17	0.596	0.434
11-Jan	18	0.51	0.392
24-Jan	19	0.526	0.336
2-Feb	20	0.386667	0.214667
10-Feb	21	0.314	0.234
16-Feb	22		
22-Feb	23		
6-Mar	24	0.669333	0.458667
9-Mar	25		
16-Mar	26	0.417333	0.298667
23-Mar	27	0.2	0.152
30-Mar	28	0.2858	0.2588

8.2.3 Column 3 (16 weeks pre treated waste coarse)

Date	Weeks	TS	VS
13-Sep	1	2.6274	1.32
21-Sep	2	1.374	0.854
27-Sep	3	0.7265	0.366
4-Oct	4	0.7	0.51
11-Oct	5	0.162	0.35
19-Oct	6	0.304	
25-Oct	7	0.316	
1-Nov	8	0.24	
9-Nov	9		
15-Nov	10		
21-Nov	11		
29-Nov	12	0.904	0.728
6-Dec	13		
15-Dec	14	0.296	0.054
22-Dec	15		
28-Dec	16	0.166	0.112
5-Jan	17		
11-Jan	18	0.178667	0.116
24-Jan	19		
2-Feb	20	0.269333	0.053333
10-Feb	21		
16-Feb	22		
22-Feb	23		
6-Mar	24	0.254667	0.092
9-Mar	25		
16-Mar	26	0.177333	0.104
23-Mar	27		
30-Mar	28	0.126	0.206

8.2.4 Column 4 (8 weeks pre treated waste fine)

Date	Weeks	TS	VS
15-Dec	1	7.57	4.238
22-Dec	2	5.82	3.228
28-Dec	3	2.988	1.756
5-Jan	4	2.076	1.272
11-Jan	5	1.62	0.962667
24-Jan	6	1.436	0.902
2-Feb	7	1.074667	0.690667
10-Feb	8	0.744	0.466
16-Feb	9		
22-Feb	10		
6-Mar	11	0.724	0.501333
9-Mar	12		
16-Mar	13	0.52	0.390667
23-Mar	14	6.834	6.056
30-Mar	15	1.346	1.006
6-Apr	16		
13-Apr	17	19.79723	0.462667
20-Apr	18		
2-May	19	0.545333	0.274667
9-May	20		
16-May	21	0.232	0.096
23-May	22		
31-May	23	0.376	0.181333
6-Jun	24		
13-Jun	25	0.294667	0.168
20-Jun	26		
27-Jun	27	0.672	0.026667
4-Jul	28		
11-Jul	29	0.404	0.182667
25-Jul	30		
2-Aug	31		
8-Aug	32	0.172	0.1321

8.2.5. Column 5 (8 weeks pre treated waste coarse)

Date	Weeks	TS	VS
15-Dec	1	5.752	2.98
22-Dec	2	6.296	4.704
28-Dec	3	3.396	2.296
5-Jan	4	1.476	1.194
11-Jan	5	1.434667	0.804
24-Jan	6	0.732	0.35
2-Feb	7	0.764	0.446667
10-Feb	8	0.588	0.288
16-Feb	9		
22-Feb	10		
6-Mar	11	1.657333	1.304
9-Mar	12		
16-Mar	13	0.586667	0.433333
23-Mar	14	0.19	0.214
30-Mar	15		
6-Apr	16		
13-Apr	17	20.11003	0.258667
20-Apr	18		
2-May	19		
9-May	20		
16-May	21	0.150667	0.069333
23-May	22		
31-May	23	0.32	0.166667
6-Jun	24		
13-Jun	25	0.217333	0.12
20-Jun	26		
27-Jun	27	0.076	0.009333
4-Jul	28		
11-Jul	29	0.166667	0.076
25-Jul	30		
2-Aug	31		
8-Aug	32	0.329333	0.125333

TS and VS expressed in g/l (average)

8.3 COD

8.3.1 Column 1 (Fresh Waste)

Date	Weeks	COD
23-May	1	11320.71
31-May	2	19151.52
6-Jun	3	18893.64
13-Jun	4	18842.07
20-Jun	5	17879.33
27-Jun	6	5252.054
4-Jul	7	13555.63
11-Jul	8	2063
18-Jul	9	
25-Jul	10	11991.19
2-Aug	11	10349.38
8-Aug	12	9644.525
15-Aug	13	18154.4
22-Aug	14	9283.5
27-Aug	15	9438.225
5-Sep	16	7658.888
12-Sep	17	
19-Sep	18	6878.042
26-Sep	19	6104.417
3-Oct	20	6232.323

8.3.2 Column 2 (16 weeks pre treated waste fine)

Date	Weeks	COD
13-Sep	1	7080.746
21-Sep	2	5077.646
27-Sep	3	4153.85
4-Oct	4	3998.5
11-Oct	5	2535.5
19-Oct	6	1470
25-Oct	7	1448.5
1-Nov	8	734.5
9-Nov	9	375
15-Nov	10	278
21-Nov	11	260
29-Nov	12	178
6-Dec	13	169
15-Dec	14	167
22-Dec	15	143.5
28-Dec	16	128
5-Jan	17	98
11-Jan	18	111
24-Jan	19	58
2-Feb	20	42.25
10-Feb	21	83.45
16-Feb	22	62.7152
22-Feb	23	84.9956
6-Mar	24	80.8696
9-Mar	25	84.3767
16-Mar	26	76.7436
23-Mar	27	79.8381
30-Mar	28	70.5546

8.3.3 Column 3 (16 weeks pre treated waste coarse)

Date	Weeks	COD
13-Sep	1	1662.685
21-Sep	2	909.3168
27-Sep	3	651.9231
4-Oct	4	685.71
11-Oct	5	508
19-Oct	6	365.75
25-Oct	7	428
1-Nov	8	215.5
9-Nov	9	
15-Nov	10	283
21-Nov	11	
29-Nov	12	210.75
6-Dec	13	
15-Dec	14	150
22-Dec	15	
28-Dec	16	156.5
5-Jan	17	
11-Jan	18	80.5
24-Jan	19	
2-Feb	20	93.25
10-Feb	21	
16-Feb	22	69.3168
22-Feb	23	
6-Mar	24	77.5688
9-Mar	25	
16-Mar	26	61.0648
23-Mar	27	
30-Mar	28	57.3514

8.3.4 Column 4 (8 weeks pre treated waste fine)

Date	Weeks	COD
15-Dec	1	4831
22-Dec	2	4267
28-Dec	3	1753
5-Jan	4	924.65
11-Jan	5	658.0333
24-Jan	6	403.5
2-Feb	7	243.75
10-Feb	8	221
16-Feb	9	169.166
22-Feb	10	160.0888
6-Mar	11	135.3328
9-Mar	12	136.3643
16-Mar	13	102.3248
23-Mar	14	173.292
30-Mar	15	95.3106
6-Apr	16	84.1704
13-Apr	17	61.0648
20-Apr	18	
2-May	19	82.52
9-May	20	60.4459
16-May	21	65.1908
23-May	22	69.9357
31-May	23	59.4144
6-Jun	24	48.2742
13-Jun	25	56.1136
20-Jun	26	
27-Jun	27	8.0457
4-Jul	28	36.5151
11-Jul	29	31.3576
25-Jul	30	
2-Aug	31	
8-Aug	32	44.5608

8.3.5 Column 5 (8 weeks pre treated waste coarse)

Date	Weeks	COD
15-Dec	1	4154.333
22-Dec	2	2442.9
28-Dec	3	2723
5-Jan	4	1413
11-Jan	5	1096
24-Jan	6	922.1
2-Feb	7	439.5
10-Feb	8	292
16-Feb	9	231.8812
22-Feb	10	195.5724
6-Mar	11	156.788
9-Mar	12	124.8115
16-Mar	13	102.3248
23-Mar	14	97.7862
30-Mar	15	39.197
6-Apr	16	55.2884
13-Apr	17	30.945
20-Apr	18	
2-May	19	
9-May	20	27.4379
16-May	21	34.6584
23-May	22	31.1513
31-May	23	47.8616
6-Jun	24	18.567
13-Jun	25	40.4348
20-Jun	26	
27-Jun	27	3.9197
4-Jul	28	19.1859
11-Jul	29	14.0284
25-Jul	30	
2-Aug	31	
8-Aug	32	29.7072

COD expressed in mg/l (average)

8.4 N-ammonical and nitrates

8.4.1 Column 1 (Fresh Waste)

Date	Weeks	NH_3	Nox
23-May	1	136.22	16.24
31-May	2	308.14	12.32
6-Jun	3	323.65	12.58
13-Jun	4	365.4	12.88
20-Jun	5	358.96	13.72
27-Jun	6	284.9	5.74
4-Jul	7	104.72	11.34
11-Jul	8	119.84	10.5
18-Jul	9	0	0
25-Jul	10	200.06	16.94
2-Aug	11	0	0
8-Aug	12	120.54	14
15-Aug	13	0	0
22-Aug	14	77	9.66
27-Aug	15	0	0
5-Sep	16	65.94	5.6
12-Sep	17	65.94	5.6
19-Sep	18	49.14	4.34
26-Sep	19	49.93333	5.6
3-Oct	20	36.12	1.96

8.4.2 Column 2 (16 weeks pre treated waste fine)

Date	Weeks	NH_3	Nox
13-Sep	1	146	6
21-Sep	2	117.3	5.5
27-Sep	3	62.1	4.8
4-Oct	4	32.5	5.2
11-Oct	5	21.9	3
19-Oct	6	12.9	4.7
25-Oct	7	6.3	3.1
1-Nov	8	5.2	2.9
9-Nov	9	5.4	4.9
15-Nov	10	4.6	6.8
21-Nov	11	5.8	5.8
29-Nov	12		
6-Dec	13	6.8	8.7
15-Dec	14	7.5	5.7
22-Dec	15	9.2	9.2
28-Dec	16	9.7	9.4
5-Jan	17	8.4	9.5
11-Jan	18	8.7	6.4
24-Jan	19		
2-Feb	20		
10-Feb	21		
16-Feb	22	2.473333	4.62
22-Feb	23	3.873333	2.566667
6-Mar	24	4.573333	5.833333
9-Mar	25	3.826667	4.853333
16-Mar	26	3.15	4.69
23-Mar	27		
30-Mar	28	3.52	1.717333

8.4.3 Column 3 (16 weeks pre treated waste coarse)

Date	Weeks	NH_3	Nox
13-Sep	1	25.5024	2.8336
21-Sep	2	11.9504	3.3264
27-Sep	3	5.6672	3.5728
4-Oct	4	3.6692	5.1744
11-Oct	5	3.2035	1.9715
19-Oct	6	3.119	4.8048
25-Oct	7	3.0345	4.0656
1-Nov	8	2.95	
9-Nov	9		
15-Nov	10	4.845867	11.90933
21-Nov	11		
29-Nov	12	4.024533	
6-Dec	13		
15-Dec	14	3.2032	3.8192
22-Dec	15		
28-Dec	16	2.66	5.74
5-Jan	17		
11-Jan	18	2.8	5.32
24-Jan	19		
2-Feb	20	1.73	
10-Feb	21		
16-Feb	22	0.653333	5.133333
22-Feb	23		
6-Mar	24	1.773333	3.5
9-Mar	25		
16-Mar	26	1.54	6.02
23-Mar	27		
30-Mar	28	2.893333	2.408

8.4.4 Column 4 (8 weeks pre treated waste fine)

Date	Weeks	NH_3	Nox
15-Dec	1	56.3	8.8704
22-Dec	2	22.4	3.8192
28-Dec	3	6.2	10.08
5-Jan	4	7.4	
11-Jan	5	8.7	4.76
24-Jan	6	16	4.48
2-Feb	7	16	
10-Feb	8	16.1	
16-Feb	9	16.1	8.12
22-Feb	10	19.22667	4.293333
6-Mar	11	17.54667	16.05333
9-Mar	12	14.28	16.05333
16-Mar	13	13.16	19.6
23-Mar	14		
30-Mar	15	17.08	16.89333
6-Apr	16		
13-Apr	17	7.42	11.48
20-Apr	18		
2-May	19	8.82	18.9
9-May	20		
16-May	21	5.88	13.58
23-May	22		
31-May	23	5.6	16.52
6-Jun	24		
13-Jun	25	6.16	15.82
20-Jun	26		
27-Jun	27	9.38	4.76
4-Jul	28		
11-Jul	29	6.72	11.34
25-Jul	30		
2-Aug	31		
8-Aug	32	5.46	9.52

8.4.5 Column 5 (8 weeks pre treated waste coarse)

Date	Weeks	NH_3	Nox
15-Dec	1	70.9	9.1168
22-Dec	2	26	4.0656
28-Dec	3	3.6	4.3
5-Jan	4	3.9	4.5
11-Jan	5	4.2	4.76
24-Jan	6	3.6	4.48
2-Feb	7	3.5	6.7
10-Feb	8	3.3	8.8
16-Feb	9	3.08	11.01333
22-Feb	10	2.706667	11.01333
6-Mar	11	4.853333	12.41333
9-Mar	12	3.64	10.17333
16-Mar	13	5.88	22.54
23-Mar	14		
30-Mar	15		
6-Apr	16		
13-Apr	17	5.74	4.2
20-Apr	18		
2-May	19	4.06	15.12
9-May	20		
16-May	21	4.06	11.76
23-May	22		
31-May	23	4.76	19.6
6-Jun	24		
13-Jun	25	4.34	19.88
20-Jun	26		
27-Jun	27	3.78	7.14
4-Jul	28		
11-Jul	29	4.48	13.3
25-Jul	30		
2-Aug	31		
8-Aug	32	3.78	10.64

NH3 and Nox expressed in mg/l (average)